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A MULTI-USE LOAD SYSTEM FOR ROCK TESTING

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A MULTI-USE LOAD SYSTEM FOR ROCK TESTING

by

B. Gorski*

ABSTRACT

A multi-use compression press has been fabricated in-house at the Rock Mechanics Laboratory of CANMET. The test system has been used successfully to conduct triaxial tests on rock specimens. The test system incorporates a novel triaxial chamber located within the main body of the loading ram. The system is readily adaptable to perform non-conventional tests. The multi-use test system's design and operation is described in this report.

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UNE INSTALLATION DE CHARGEMENT MULTITÂCHE POUR EFFECTUER
DES ESSAIS DE ROCHE

par

B. Gorski*

RÉSUMÉ

Une presse de compression multitâche a été fabriquée sur place au Laboratoire de la mécanique des roches du CANMET. L'installation d'essai a été utilisée avec succès pour effectuer des essais triaxiaux sur des échantillons de roche. L'installation d'essai comprend une chambre triaxiale originale située à l'intérieur de la section principale du béliet hydraulique de chargement. L'installation est facilement adaptable afin de permettre des essais non classiques. La conception et le mode de fonctionnement de cette installation multitâche sont décrits dans le présent rapport.

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1. INTRODUCTION

Laboratory studies in the field of rock mechanics at times require the use of new test methods. Equipment with the required versatility is not commercially available. Therefore, MRL has undertaken to design and fabricate a multi-use test system. The main objective in the development of the test system was to ensure adaptability of the test system to suit various anticipated laboratory studies. A secondary objective for the development of the test system was to use it for conventional rock tests.

The multi-use test system shown in Figure 1 was designed and fabricated in-house. Several of the components were acquired commercially. The basic test components are a load frame, a triaxial chamber, a loading ram, a hydraulic loading system and a control panel. The test system has been in use since December of 1985.

Design features of the system are presented in this report. Selected calibrations and tests are also included.

2. TEST SYSTEM REQUIREMENTS

The multi-use test system was designed, in principle, as a compression press. The mechanical rock property testing which will be carried out using the test system require that it be designed to meet the following performance specifications:

- (a) test 'BX' rock specimens having length to diameter ratios of 2:1,
- (b) maintain or vary confinement pressures up to 140 MPa,
- (c) apply up to 1.4 MN axial load,
- (d) axial load cycle with automatic partial unloading,
- (e) vary axial loading rates,
- (f) measure rock permeability,
- (g) measure rock axial strain under confinement,
- (h) measure rock diametric strain under confinement,
- (i) measure post peak rock axial strain,
- (j) measure sample dilation,
- (k) hold axial load and
- (l) variable load frame stiffness.

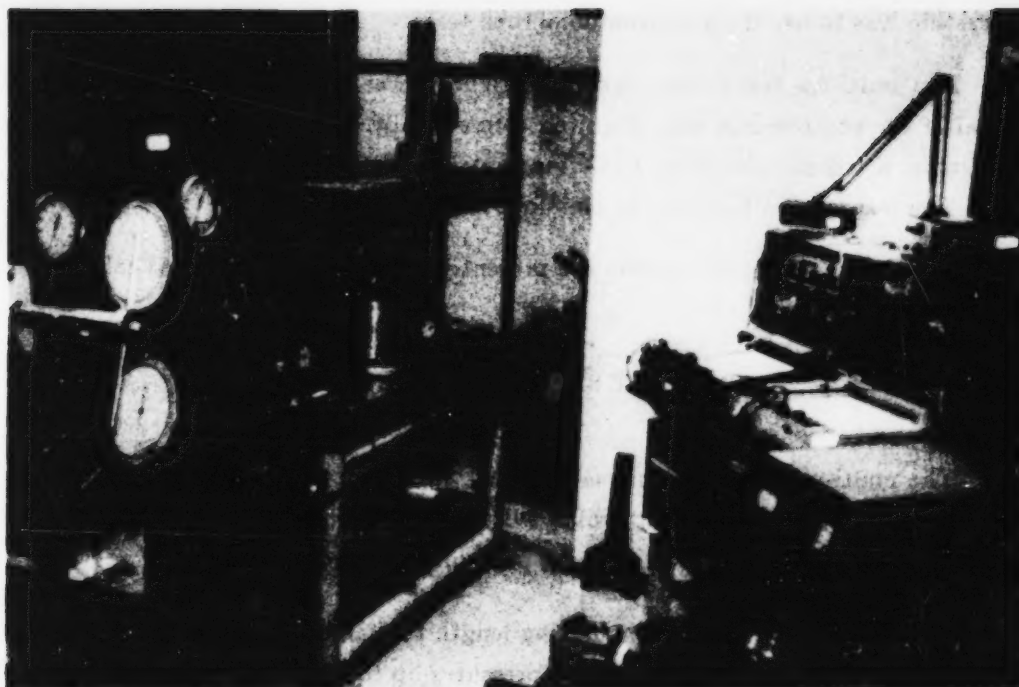


Figure 1. Photograph of the multi-use test system

Routine rock testing must fulfill standards for tests as documented in ISRM, ASTM and CANMET Pit Slope Manuals [1, 2, 3]. The standard tests to be undertaken using the test system are the following:

- (a) to conduct direct tensile strength tests,
- (b) to conduct Brazilian tensile strength tests,
- (c) to conduct uniaxial compressive strength tests,
- (d) to conduct triaxial strength tests,
- (e) to conduct multi-stage triaxial strength tests,
- (f) to conduct creep tests.

3. DESIGN AND CONSTRUCTION

LOADING FRAME

Figure 2 displays the basic test system in readiness for a triaxial test. Figure 3 displays a partial cut-away schematic drawing of the test system. The components are also listed.

The load frame clear test window width is 61 cm. The upper crosshead is adjustable to a maximum clear height of 74 cm. The 101 mm thick mild steel crosshead is raised and lowered using the outer columns (see Figure 4). The inner columns restrain load and are rated at 1400 kN load. 152 mm thick nuts having square thread design lock the crosshead to the restraint columns. The 101 mm thick pressbed is welded to the tubular steel press support. The restraint columns are bolted to the pressbed using 152 mm thick nuts.

The loading ram is seated on a 25mm thick levelling plate. The levelling plate is seated on the press bed with cement. The loading ram body is 508 mm in diameter, 229 mm high and 51 mm thick. The ram piston is 406 mm in diameter and 280 mm thick. The ram piston seal is a dual Parker O-ring design. The ram piston is dual-ported for confinement fluid pressure to the triaxial chamber. The ram body is dual-ported for fluid pressure to the ram body.

The triaxial chamber is located centrally in the ram piston. The triaxial chamber is 76 mm in diameter and 203 mm deep. The triaxial piston is 76 mm in diameter (see Figure 5). One end consists of a tapered platen 45 mm in diameter. Rock specimens contact the platen end. The triaxial piston seal is dual Parker O-ring design. The piston is dual-ported to accommodate electrical feed-throughs via Conax connectors. The piston has an additional two ports to allow permeability measurements. A clamping ring mounted on the free end of the piston accommodates the axial LVDT transducers.

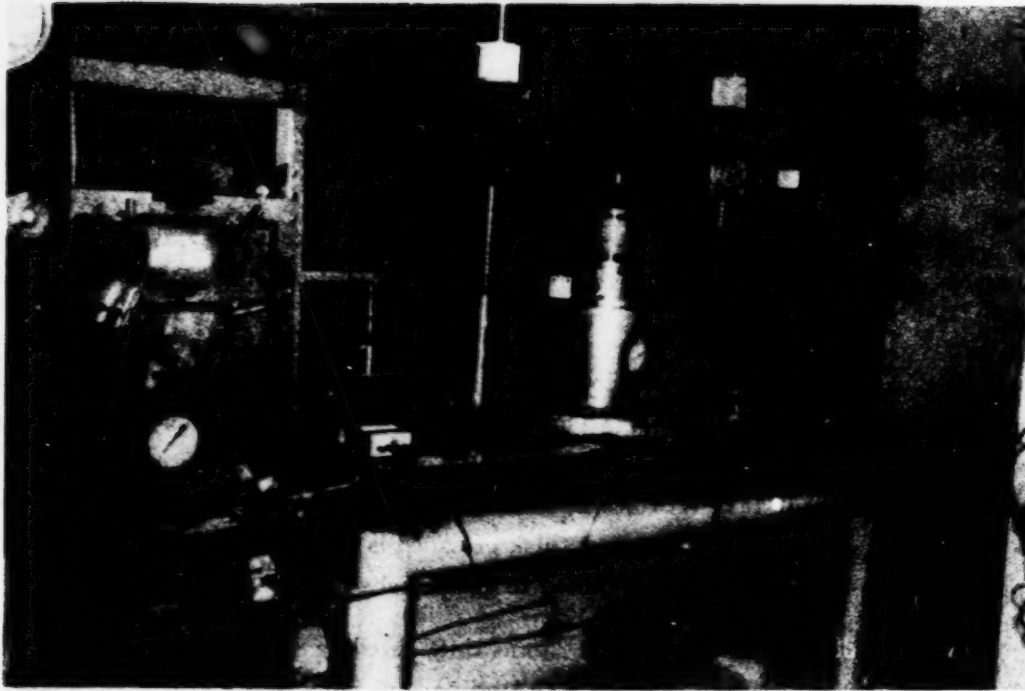


Figure 2. The loading frame

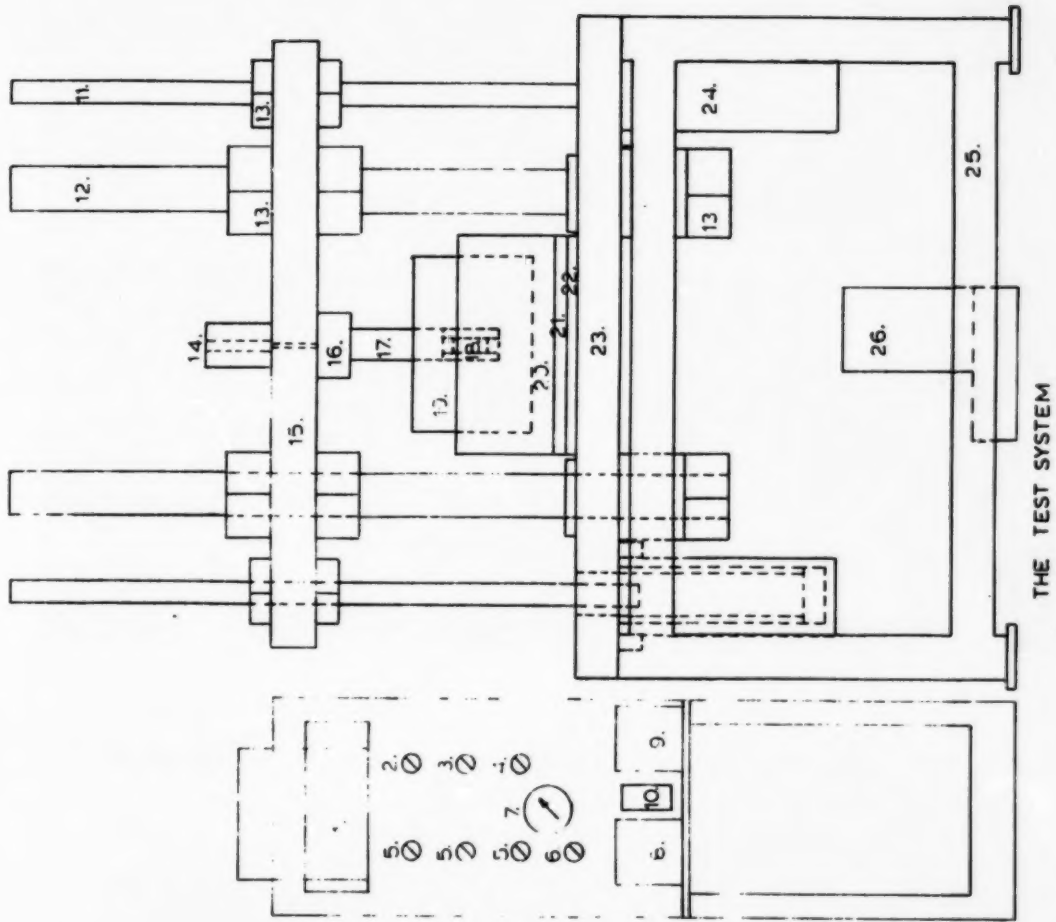


Figure 3. Schematic of the test system

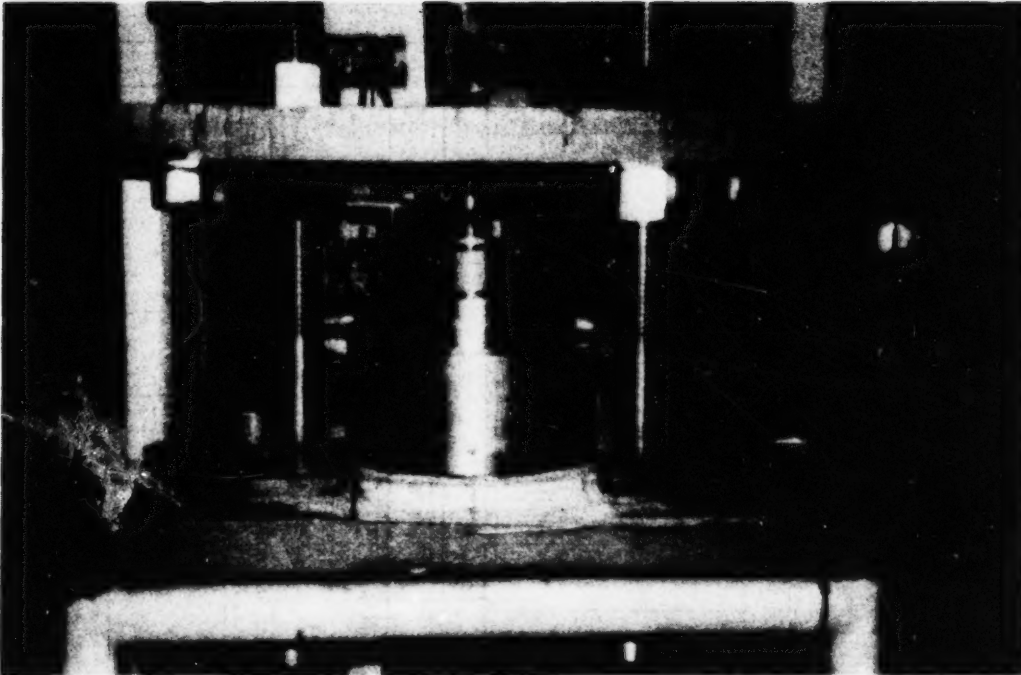


Figure 4. The outer raise columns and inner restraint columns

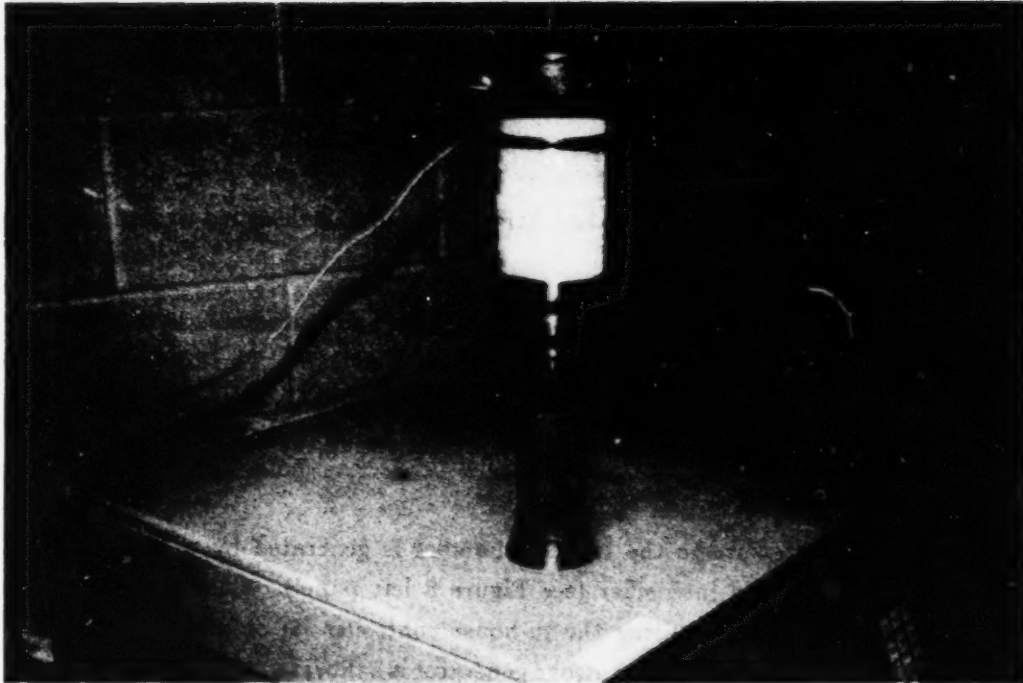


Figure 5. The triaxial piston assembly

Schnorr disc springs loaded in parallel with the test specimen provide the means to vary the press stiffness [4]. Up to six 200 mm by 112 mm by 16 springs (see Figure 6) may be used in a test; the number is varied according to the stiffness required.

SYSTEM HYDRAULICS

Figure 7 displays the hydraulic controls. Two two-way jacks are used to raise and lower the crosshead. One of these two jacks may be used independently to conduct direct tension tests. An Enerpac electric hydraulic pump supplies fluid pressure to the two-way jacks. Hydraulic directional valves are located on the control panel (see Figure 8 right panel).

An Eldex electric hydraulic pump supplies the ram with fluid pressure. The pump is dual channel and the flow rate may be varied from 0 to 10 ml/min under pressure. The maximum pressure rating of the pump is 34.5 MPa. The pump is designed to shut off under pressure with no loss in line pressure.

The Enerpac solenoid valve is three-way directional and is operated by a hand-held push button. The valve has a maximum pressure rating of 69 MPa. The fluid pressure line is connected to the ram. The pressure release line is connected to a hydraulic oil reservoir. Partial or full fluid pressure to the ram is released by activating the solenoid valve with the push button.

Confining fluid pressure to the triaxial chamber is generated by a Enerpac hand-jack or Enerpac air-operated intensifier (see Figure 8 left panel). Confining pressure is maintained either automatically using the in-house controller [5] or manually using the pressure stroke generator. The pressure stroke generator is calibrated so that the volumetric strain of test specimens can be monitored.

Figure 9 displays a medium pressure permeability unit. The unit was built in-house and is a stand-alone unit when used with an existing HIP pressure vessel. The permeability unit [6] is readily adaptable to the test system for pore pressure or permeability measurements. Rock permeability in the microdarcy range may be determined using this system. Constant head permeability measurements are derived using a calibrated 'bubble' tube. As an air bubble rises in the glass tube, volume displacement versus time readings are recorded. These values are then reduced to permeability units. The bubble tube circuit is shut off and pressure gauges are used for pore pressure measurements.

INSTRUMENTATION

Figure 10 displays the instrumentation schematic. Specimen axial load is determined

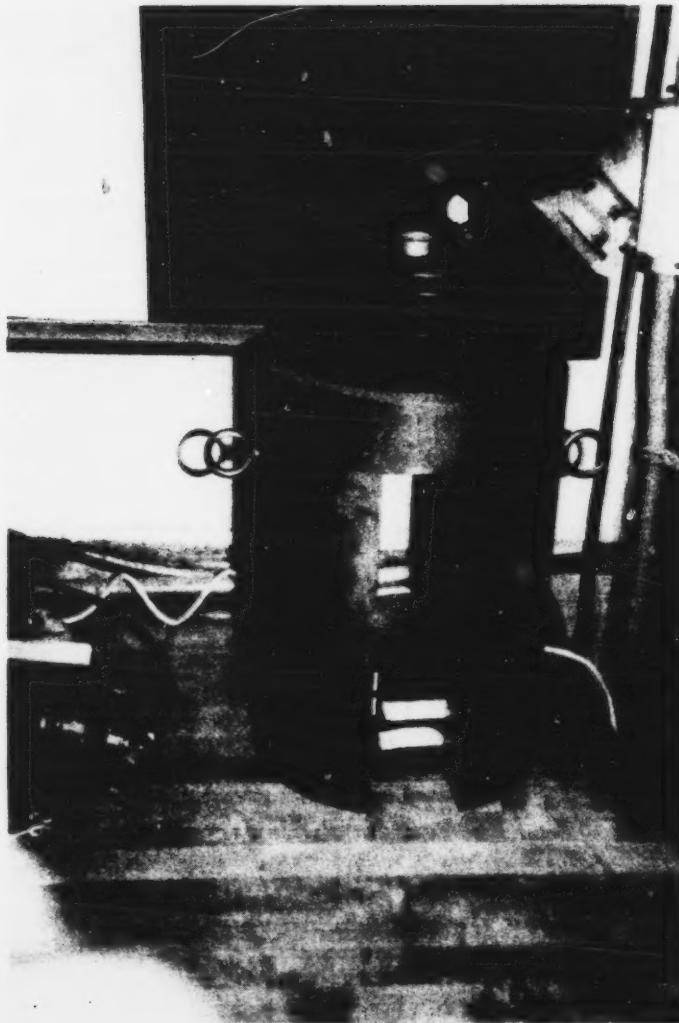


Figure 6. The disc spring assembly

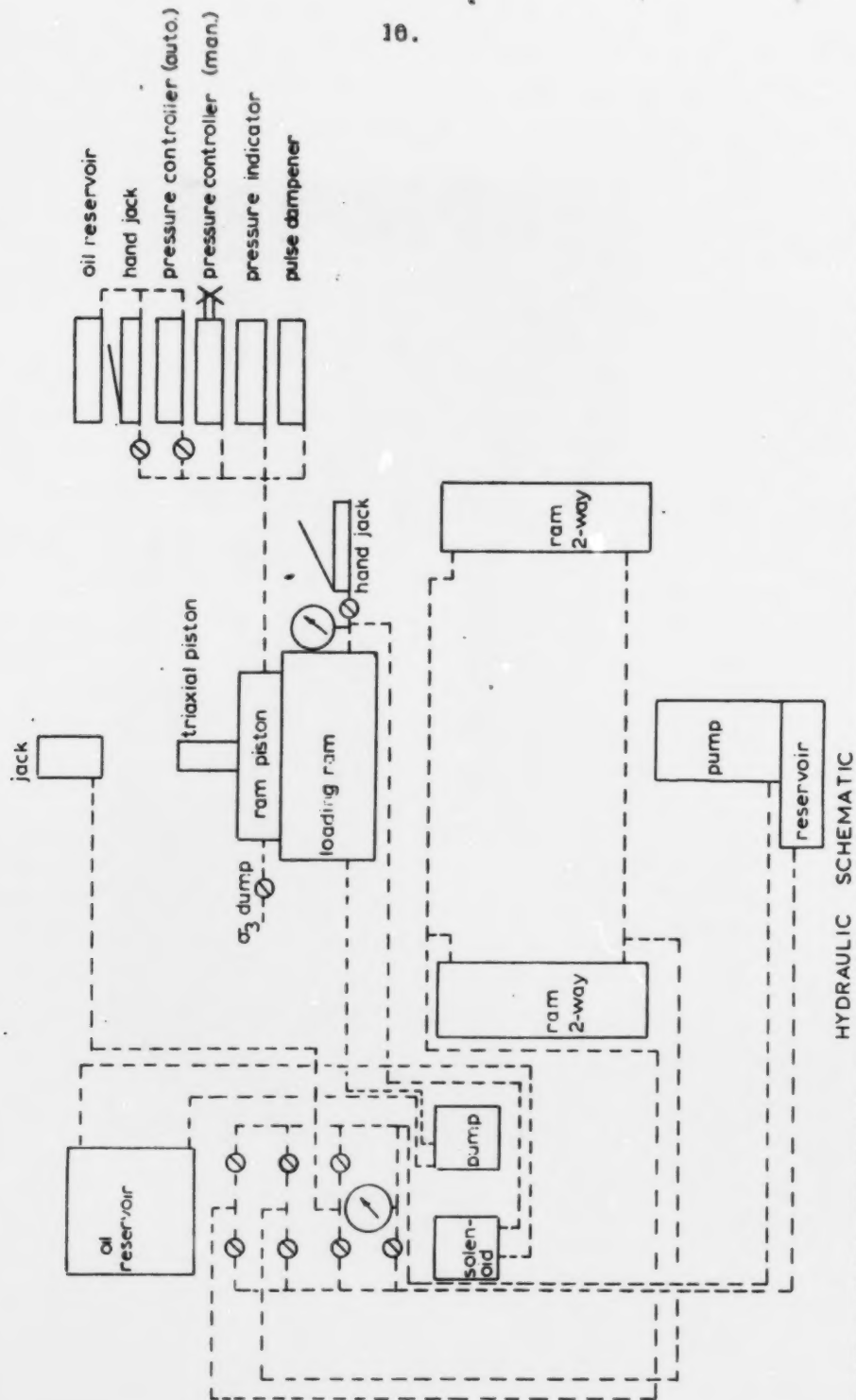


Figure 7. Schematic of the hydraulics

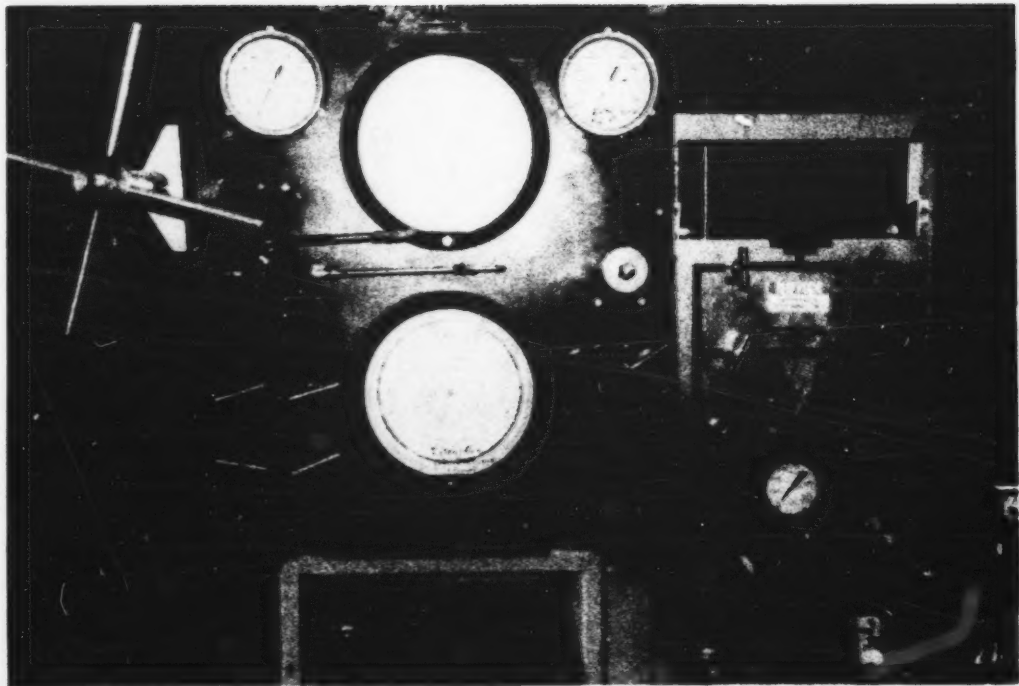


Figure 8. The hydraulic pressure control panels

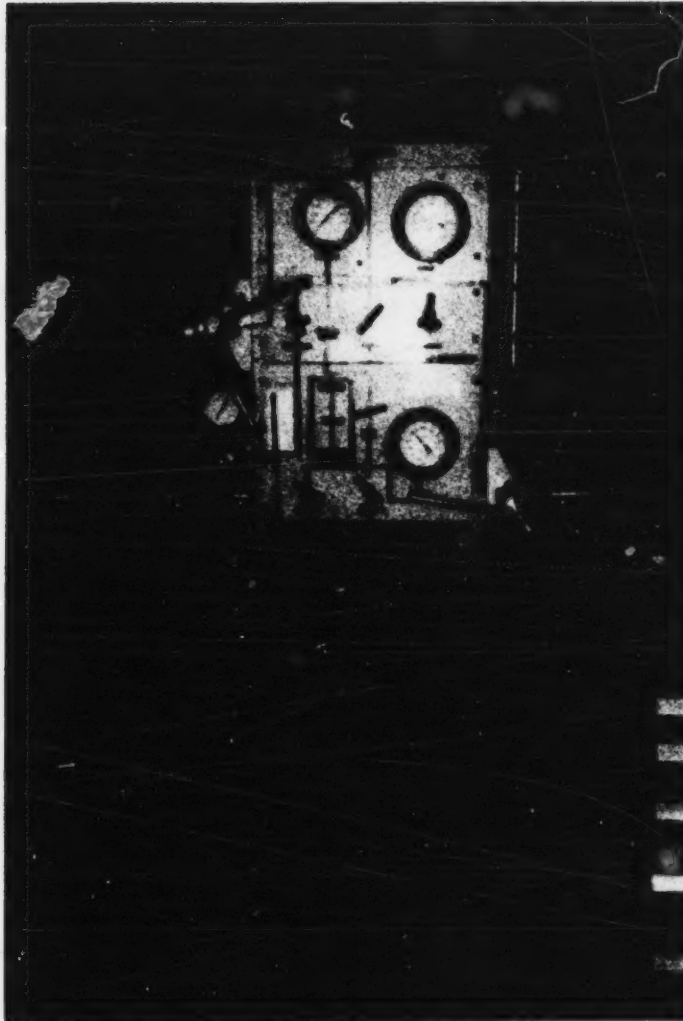
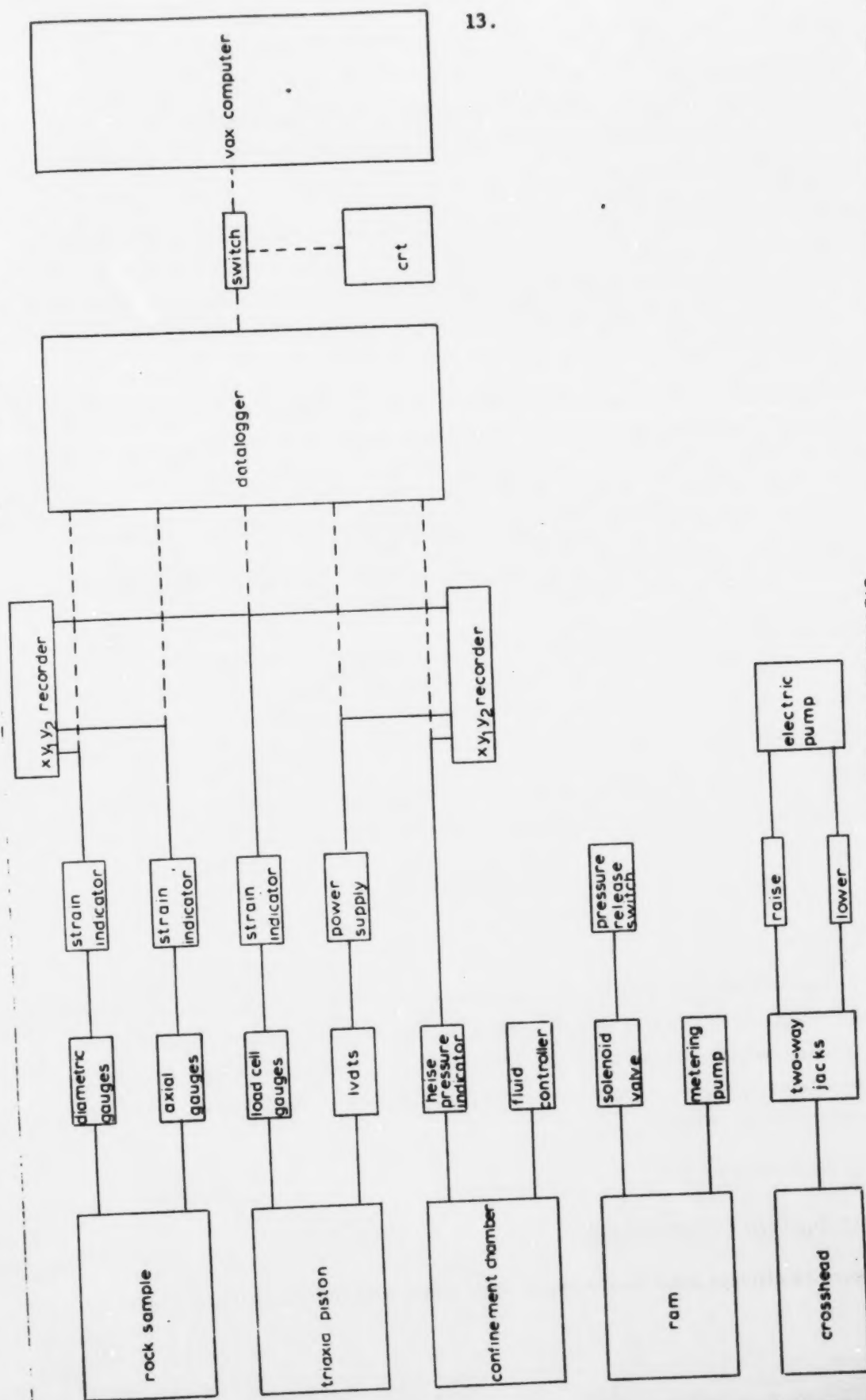


Figure 9. The permeability control panel



WIRING SCHEMATIC

Figure 10. The instrumentation schematic

from a strain bridge. The strain bridge is comprised of strain gauges glued to the surfaces of the triaxial piston. The strain bridge is wired to a B&K strain indicator for strain read-out (see Figure 11 upper 4 units).

Specimen axial displacement is determined using two linear differential transducers. The transducers are wired in series and mounted to the free end of the triaxial piston (see Figure 12). A variable power supply feeds 6 volts to the transducers. The transducers are used to determine pre-peak and post-peak specimen axial displacement during multi-stage triaxial tests.

Specimen axial and diametric strains are determined by strain gauges glued to specimen surfaces. The strain signals are wired in half bridge configurations to B&K strain indicators.

Confining fluid pressure is monitored using a Heise pressure digital indicator.

Two X, Y1, Y2 recorders are used to provide continuous traces of load, strain and displacement for specimens during testing (see Figure 11 lower left two units).

A Fluke data logger (see Figure 11 lower right unit) is used to retrieve and store data during test programs. Axial load, axial LVDT displacement, sample axial strain, sample diametric strain and confinement pressure are scanned versus a selectable time base. The raw signals are reduced to engineering units and stored on the data logger cartridge tape.

Data is transferred to a VAX 750 computer to facilitate data plotting and statistical analysis. Hard copy plots for report purposes are obtained using a laser printer.

4. CALIBRATION

LOAD CELL

The load cell strain circuit located on the surfaces of the triaxial piston (see Figure 5) provides the means of axial load measurement. The load cell was calibrated using a 1400 kN Tinius Olsen compression press. Figure 13 displays press load versus load cell strain for loading and unloading. Hysteresis is considered negligible. Strain versus load for the load cell was calculated as being:

$$2.87 \text{ micro-strain} / \text{kN}$$

TRIAXIAL PISTON COMPRESSION

Figure 14 displays axial load versus triaxial piston and end platen displacement for

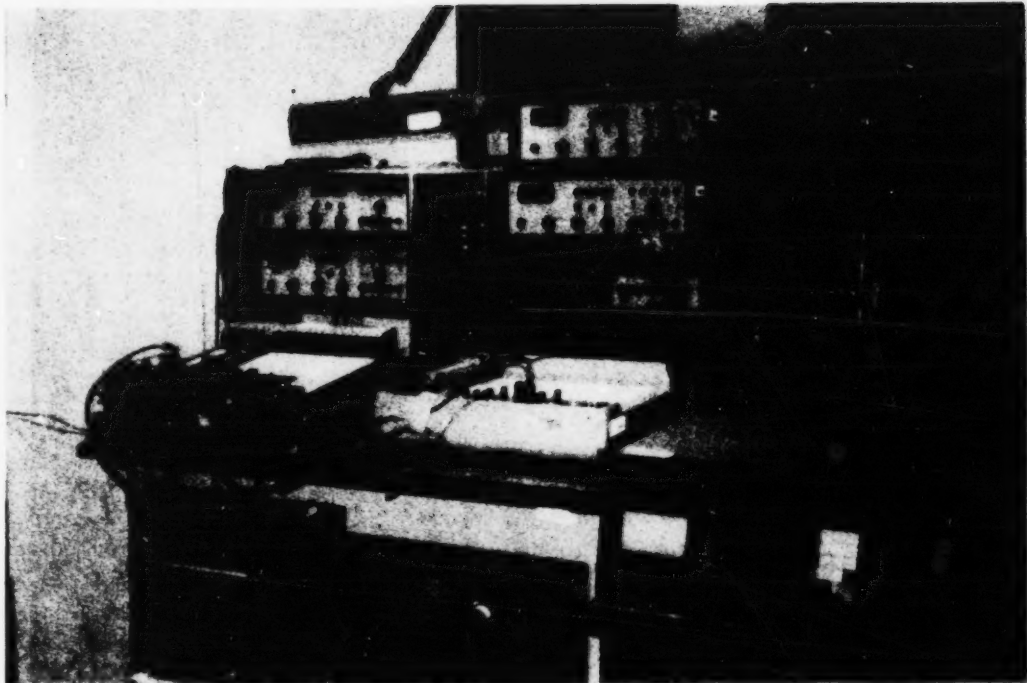


Figure 11. Instrumentation and data logging

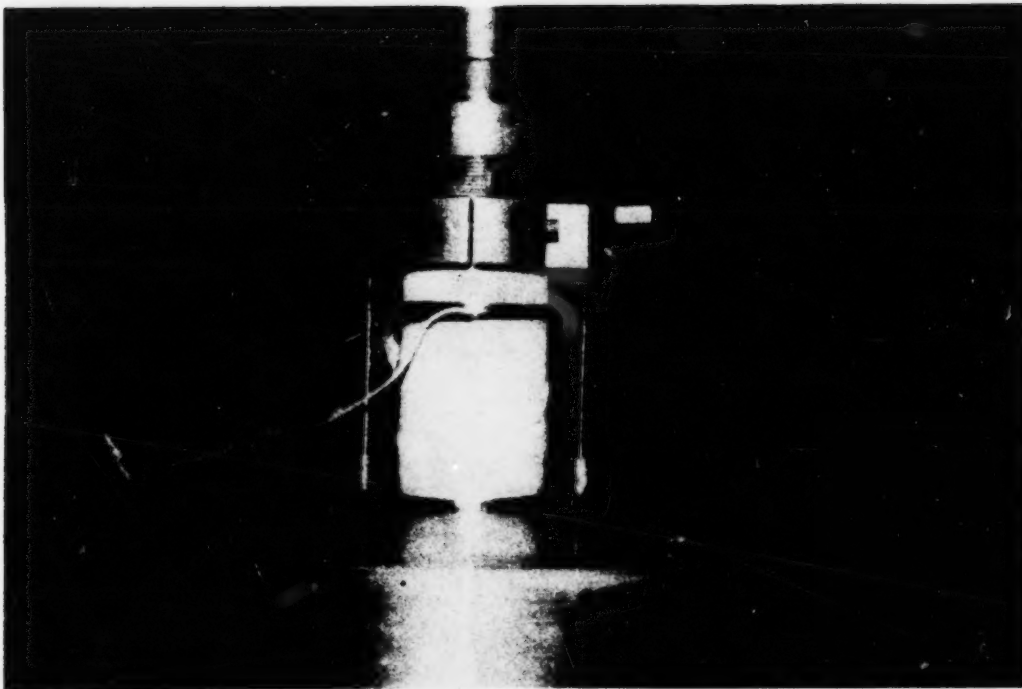


Figure 12. Transducer set-up

LOAD VERSUS TRIAXIAL PISTON LOAD CELL STRAIN

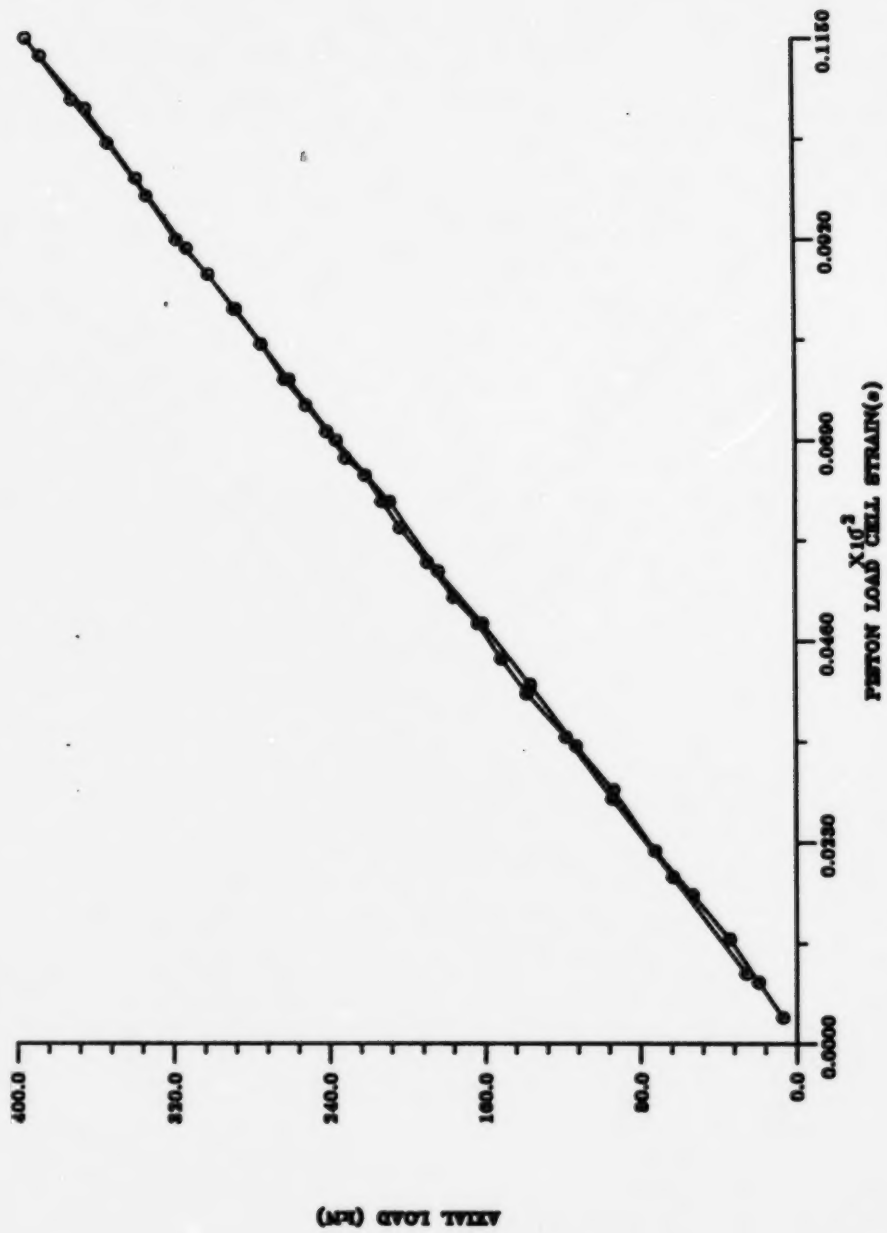


Figure 13. Load-strain plot of triaxial piston load cell

LOAD VERSUS TRIAXIAL PISTON COMPRESSION

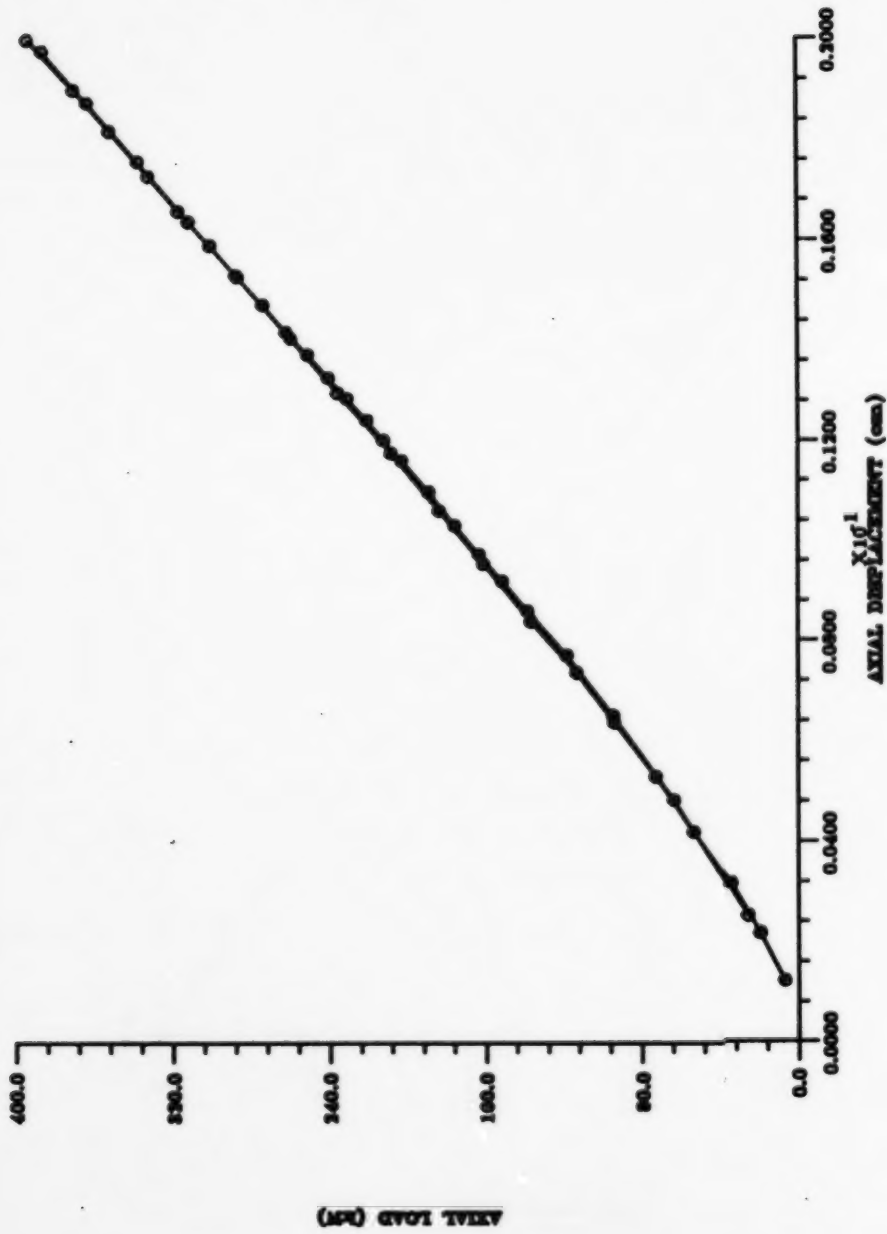


Figure 14. Load-displacement plot of triaxial piston and end platen

both loading and unloading. Hysteresis is considered negligible. Displacement versus load for the triaxial piston and end platen combined was calculated as being:

0.4436 micrometers / kN

This value is used to correct for true specimen compression.

RAM PISTON FRICTION

Figure 15 displays ram piston load versus ram piston hydraulic fluid pressure. The linear trace indicates that the ram's O-ring frictional resistance is negligible. The fluid pressure was monitored using a Heise digital pressure indicator. The load was monitored using the triaxial piston load cell. Based on the piston diameter, a 200 kN load is equivalent to a 1.54 MPa fluid pressure. The actual fluid pressure at 200 kN load was 1.52 MPa. The discrepancy between results is attributed to the greater ram body inner diameter and not due to O-ring frictional resistance. Ram load versus fluid pressure was calculated as being:

131.58 kilonewtons / megapascal

RAM PUMP LOADING RATE

Figure 16 displays maximum unrestricted ram piston travel rate using the Eldex pump. The pump was set at a maximum flow rate of 10 cc / min. The data logger was used to scan transducer displacement values every 5 seconds. The maximum travel rate was calculated as being:

72.4 micrometers / second

LOAD FRAME STIFFNESS

Figure 17 displays load versus load frame deflection. The ram was loaded against the upper crosshead in this test. Transducers were used to measure displacement. Displacement was monitored between the upper crosshead and the lower housing of the ram piston. The load frame stiffness was calculated as being:

0.54 giganewtons / meter (maximum)

CONFINING PRESSURE CORRECTION

The triaxial piston area is greater than the end area of test specimens. Loading of specimens in the triaxial state require that a correction be applied to the load cell readings. This is due to the upward load transmitted to the triaxial piston from the confinement fluid pressure. This correction is dependent on the difference in end areas of the specimen and

RAM PISTON HYDRAULIC PRESSURE VERSUS LOAD

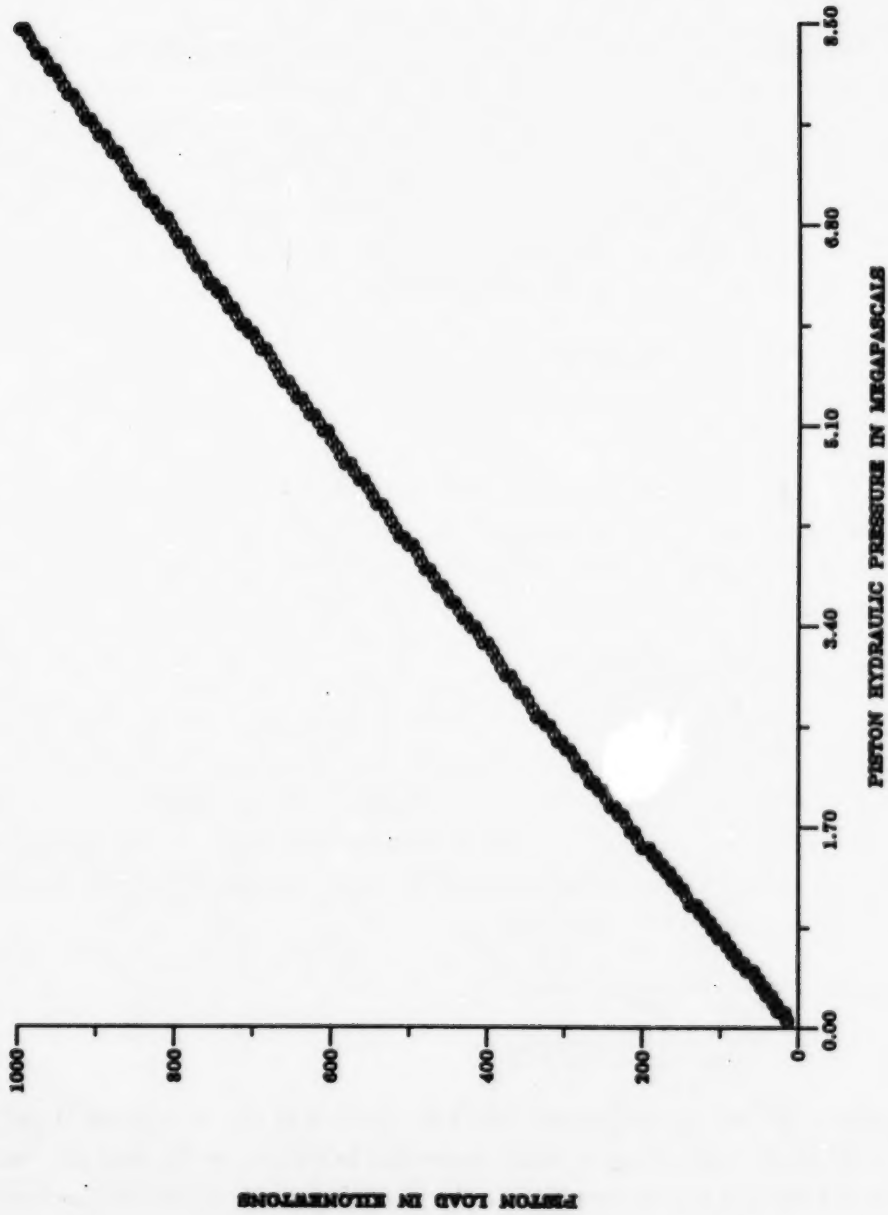


Figure 15. Load-hydraulic fluid pressure plot of ram piston

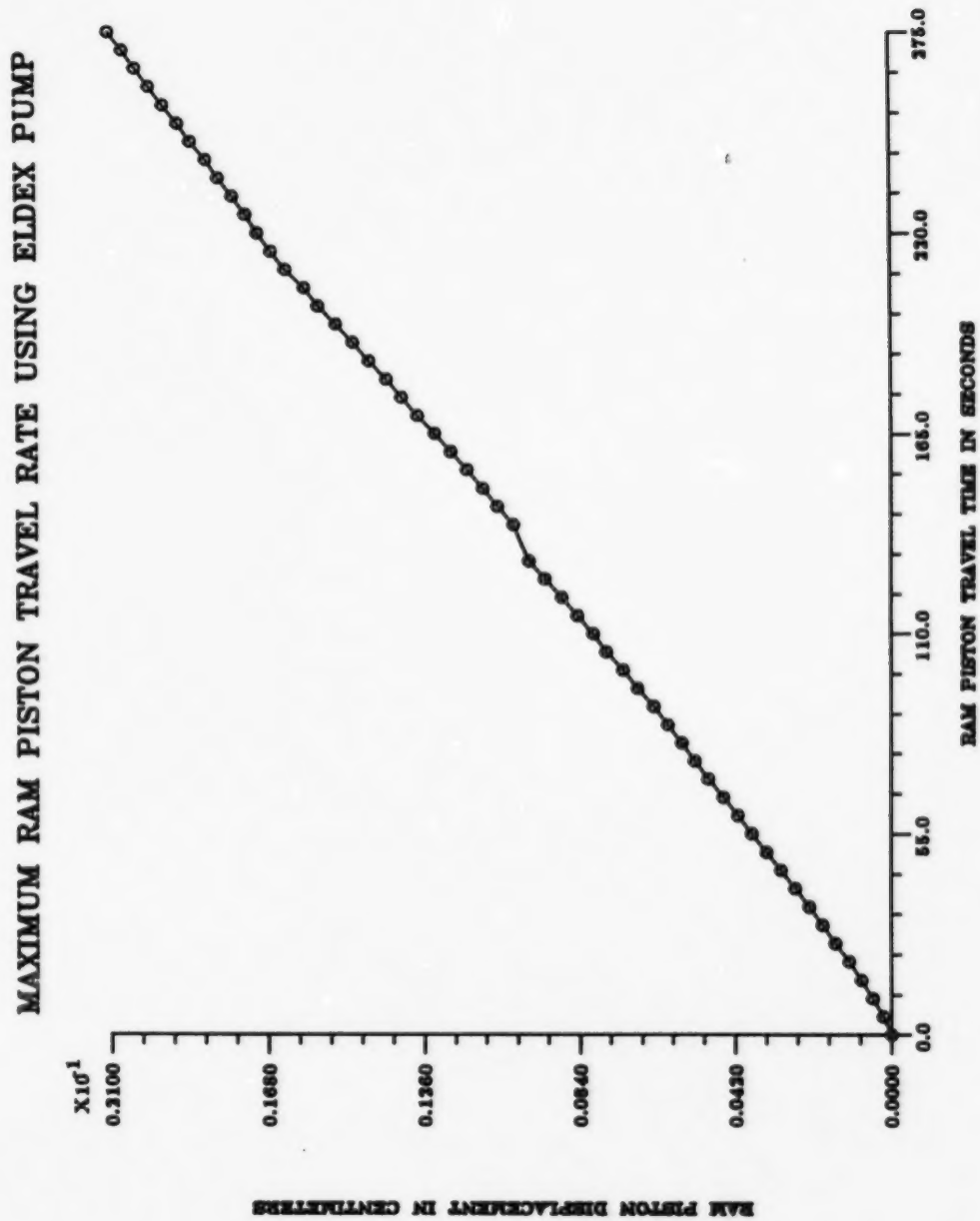


Figure 16. Displacement-travel time plot of ram piston

LOAD FRAME STIFFNESS

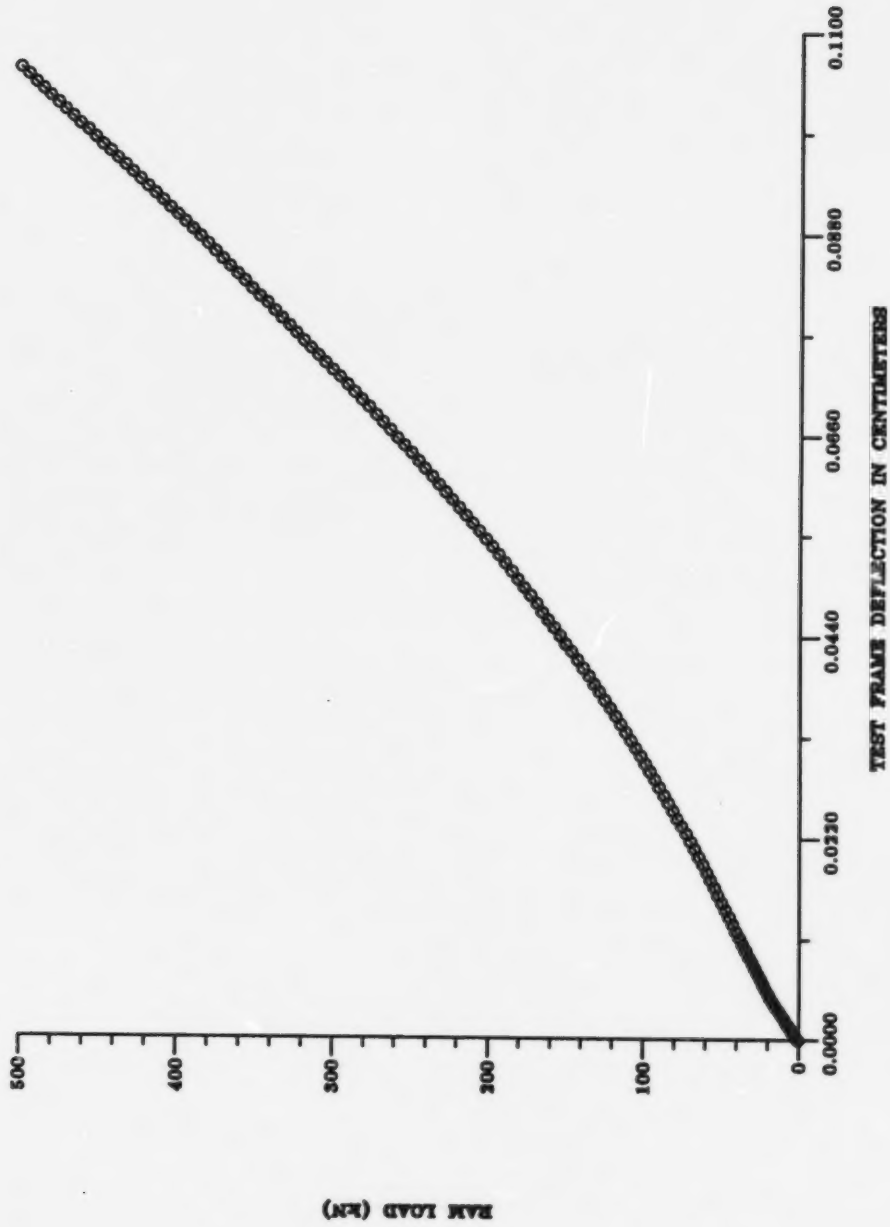


Figure 17. Load-displacement plot of load frame

TRIAXIAL PISTON LOAD VERSUS CONFINING PRESSURE

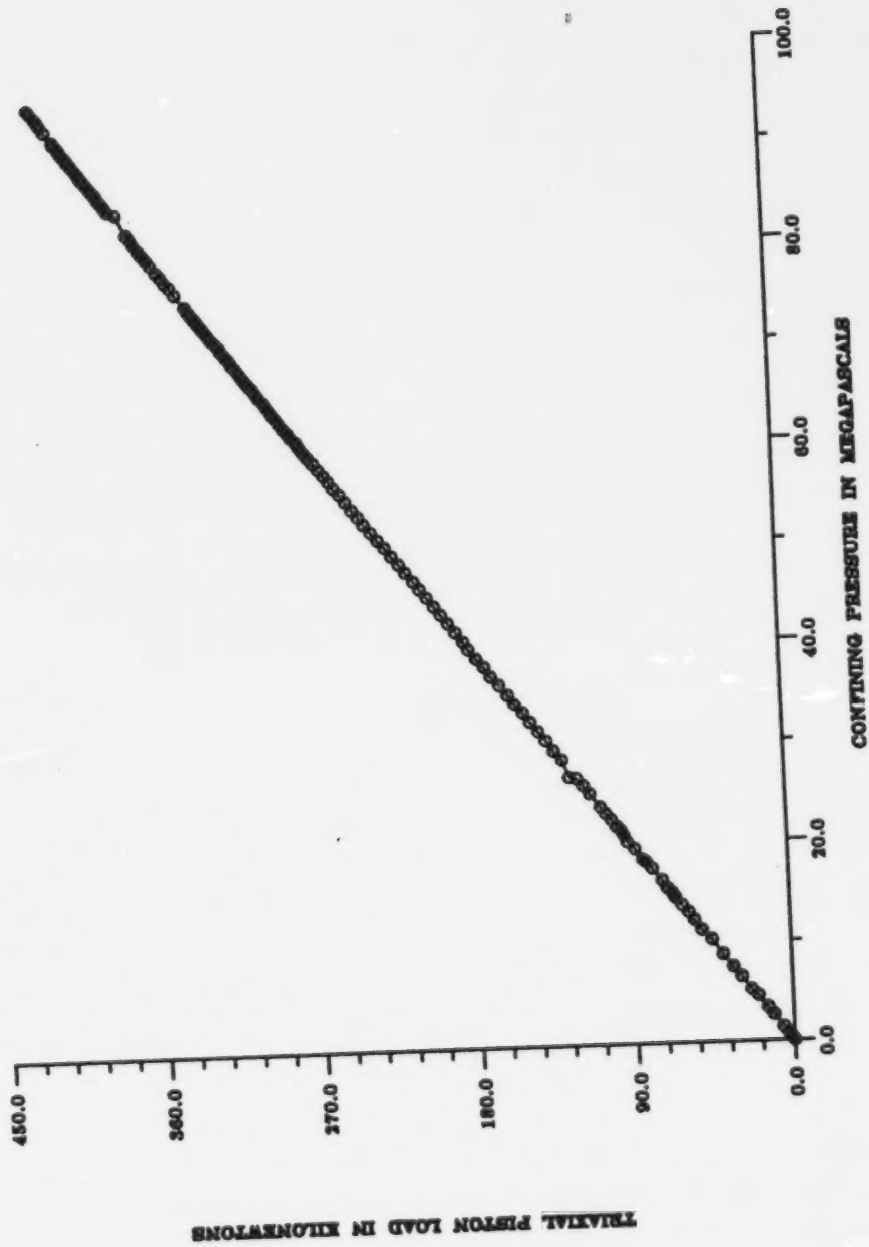


Figure 18. Load-confining pressure plot of triaxial piston

the piston, and the confining fluid pressure. Figure 18 displays load versus confining fluid pressure transmitted to the full end area of the triaxial piston. O-ring frictional resistance is not evident. The load versus confining fluid pressure correction (excluding subtraction of sample end area) was calculated as being:

$$4.52 \text{ kilonewtons / megapascal}$$

TRANSDUCER CALIBRATION

To determine the reliability of the linear variable differential transducer signals a series of uniaxial compression tests were performed on a cylindrical steel specimen of known mechanical properties. The specimen was strain gauged in the axial direction. The specimen was seated between the triaxial piston and the lower end platen. The transducers were mounted on the triaxial piston. The specimen was loaded using the test system. Figure 19 displays specimen axial load versus specimen strain. The straight line plot represents strain from the gauges glued to the specimen surfaces. The non linear plot represents strain of the specimen corrected for piston and platen compression from the transducers. The non linearity of this plot was not evident in the calibration plot shown previously in Figure 14. Young's modulus for the steel specimen was calculated using strain readings from the bonded strain gauges. The modulus value was calculated as being:

$$199 \text{ gigapascals}$$

This value compares well with the text book value. The non linearity of the transducer plot was investigated further. Figure 20 displays the data as in Figure 19 except that no corrections are applied to line 2 for piston and platen compression. The plot shows the same non linearity as in Figure 19, therefore the non linearity is not attributed to the previously applied mathematical corrections used in Figure 19.

The platen end of the triaxial piston has a thru-hole to accommodate pore pressure measurements. The reduced area due to this hole may increase specimen indentation effects thereby affecting transducer readings. A hardened steel shim was inserted between the non-hardened steel specimen and the piston end platen to reduce indentation effects. Figure 21 displays load versus specimen strain using the steel shim. The non-linearity is still prevalent.

The series of tests conducted above were performed on the premise that no eccentric specimen loading occurred. The following test was performed using a spherical seat. The steel shim was removed. Figure 22 displays load versus specimen strain from bonded strain gauges and load versus specimen strain from corrected transducer readings. The closeness of

COMPARISON OF STRAIN SIGNALS

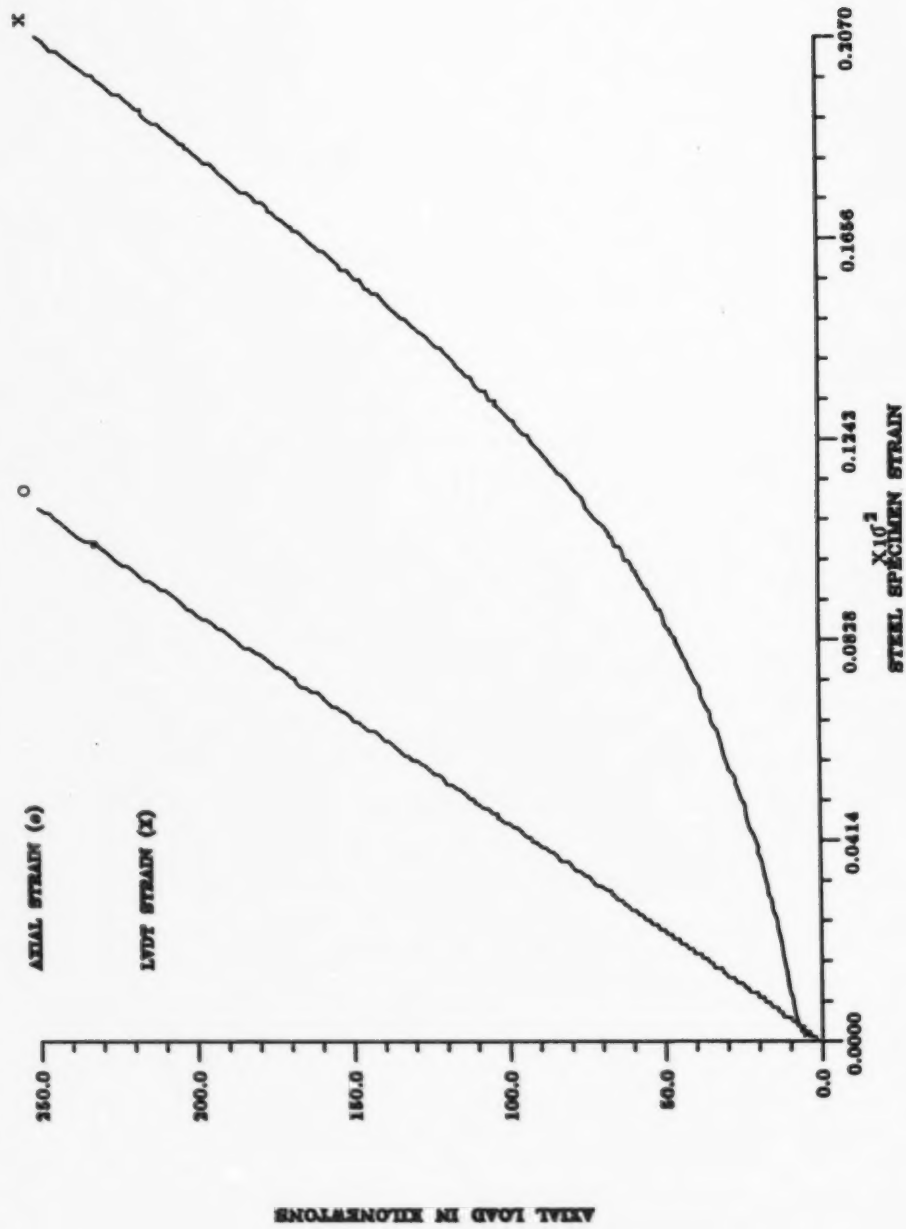


Figure 19. Load-strain plots of steel specimen

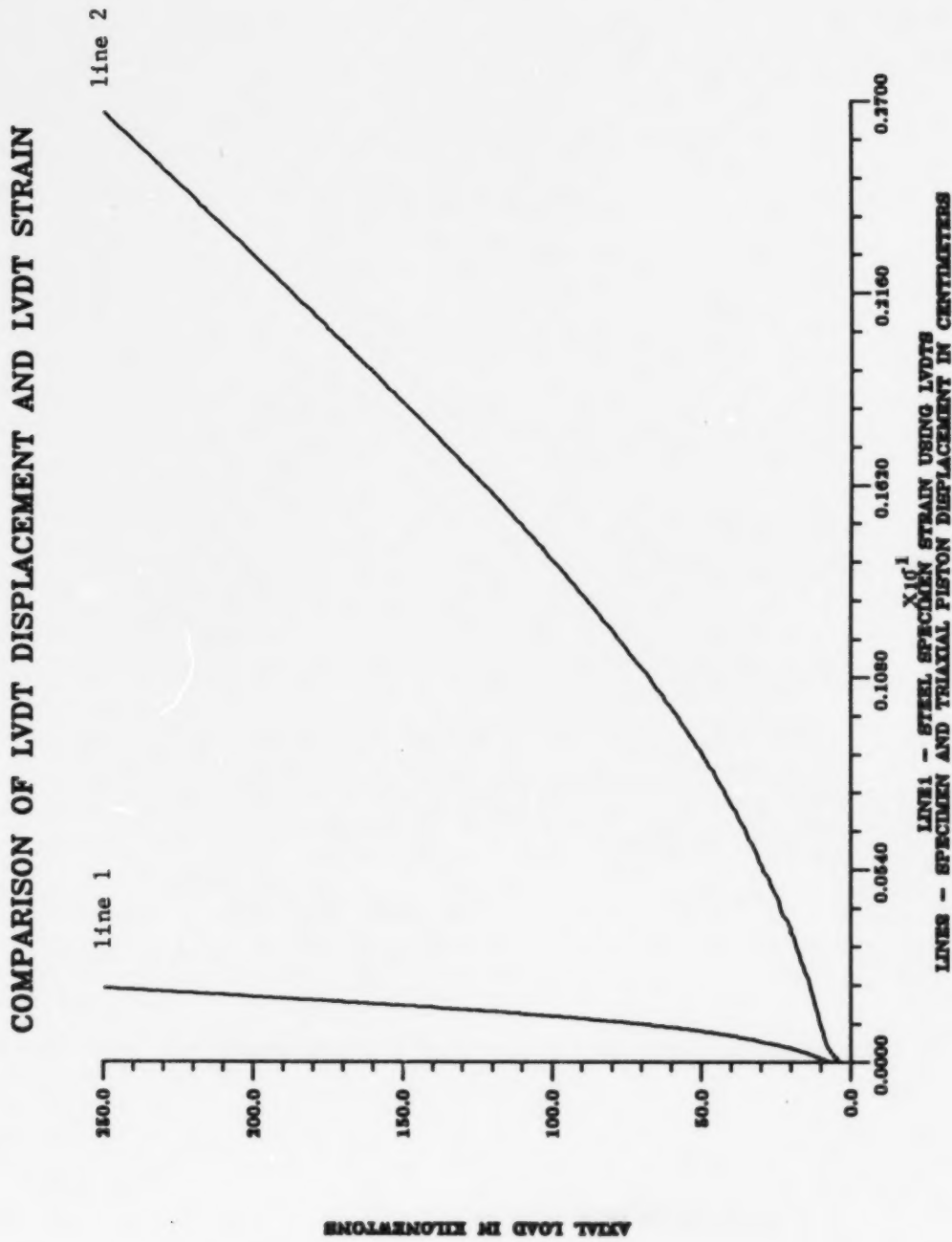


Figure 20. Load-strain & displacement plots of steel specimen

COMPARISON OF STRAIN SIGNALS

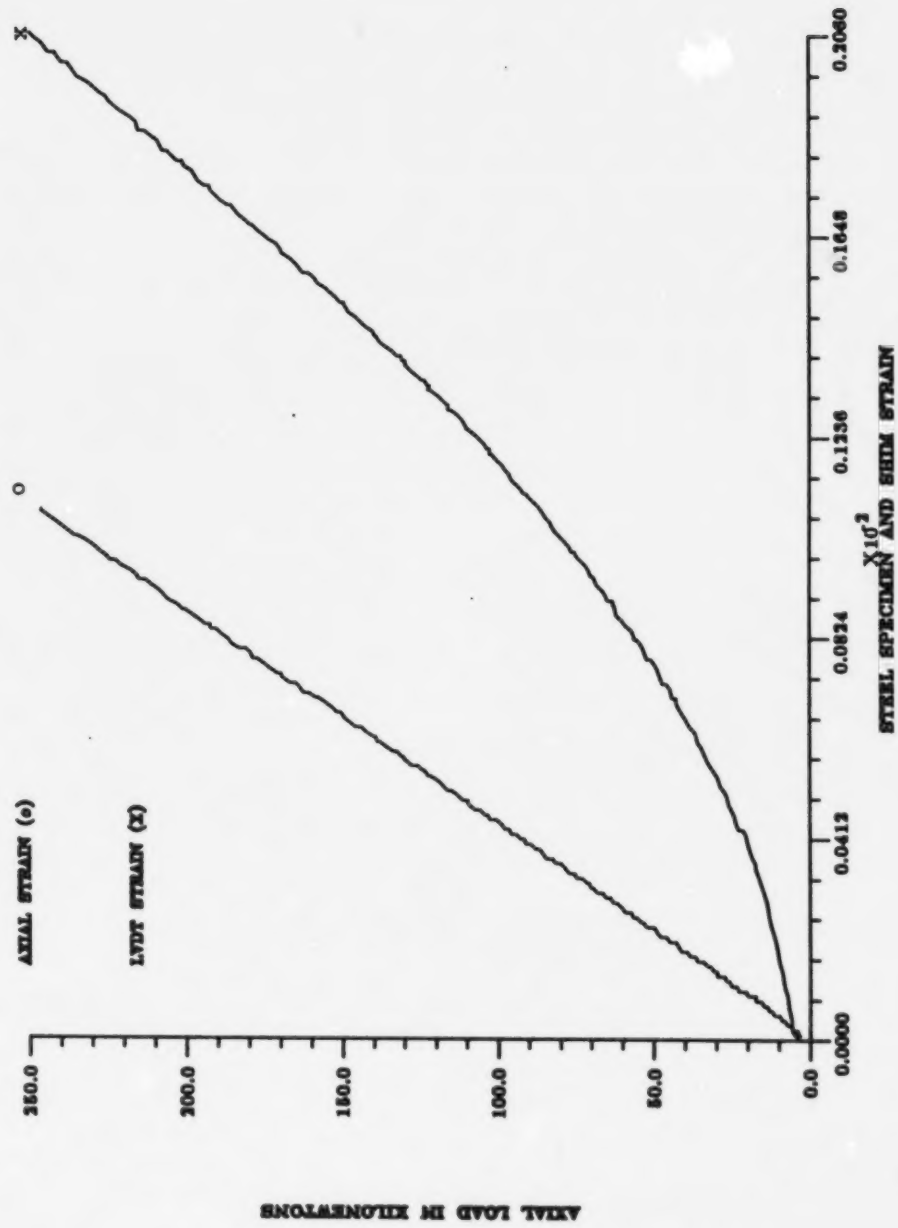


Figure 21. Load-strain plots of steel specimen and shim

COMPARISON OF STRAIN SIGNALS WITH SPHERICAL SEAT

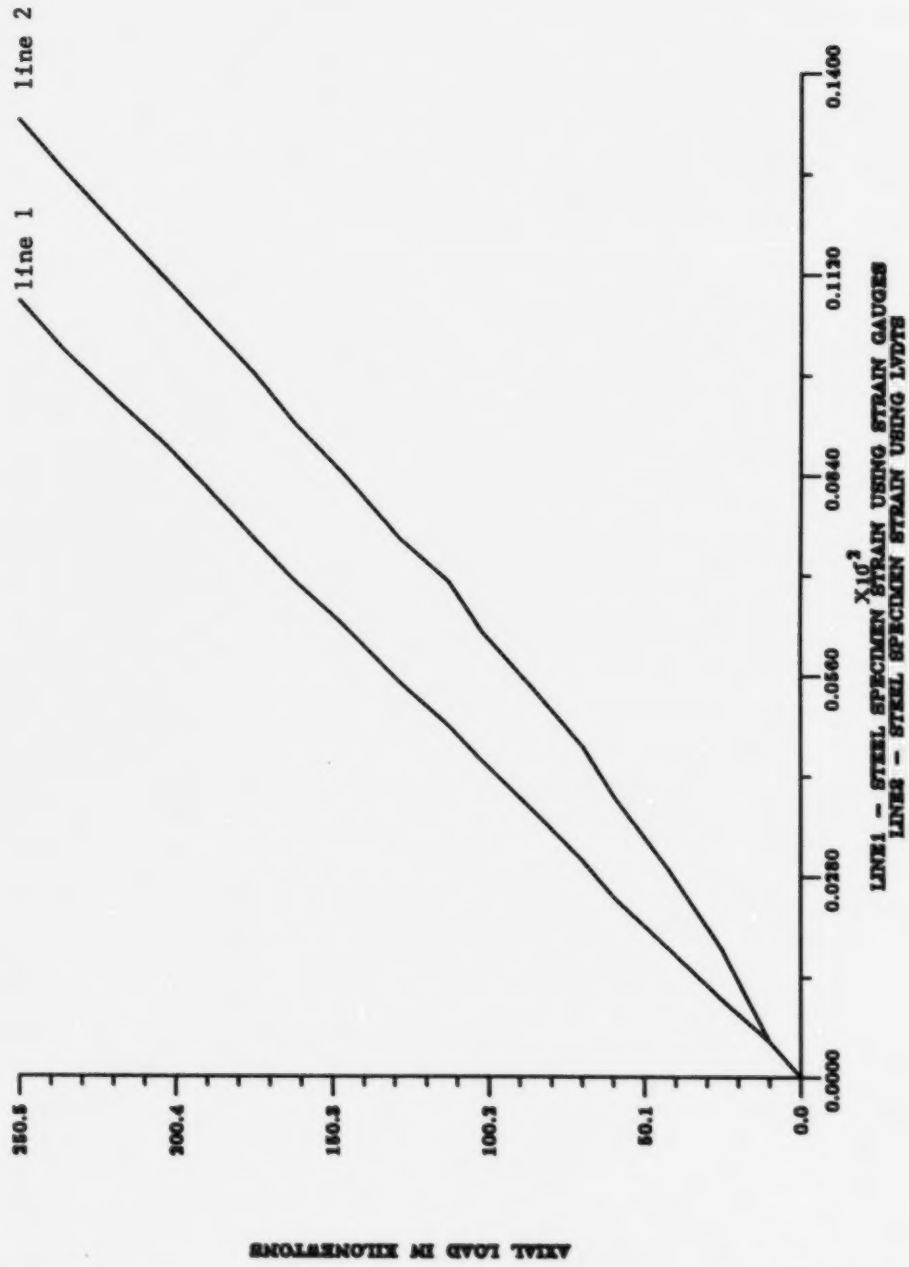


Figure 22. Load-strain plots of steel specimen using spherical seat

the plots indicate non-parallel loading of the specimen caused the non linearity of previous transducer plots. As a result, a spherical seat must be used to compensate for the non-parallel loading of specimens by the test system. Transducers may then be used with reasonable confidence for monitoring displacement.

DISC SPRINGS

The load frame stiffness is varied using disc springs. Series spring stacking decreases stiffness. Parallel spring stacking increases stiffness. The springs are loaded in series with a test specimen when a load frame stiffness less than that of the specimen is desired. The springs are loaded in parallel with the test specimen when a load frame stiffness greater than that of the specimen is desired. Table 1 gives values of stiffness for several spring stacking arrangements. Intermediate values may be obtained by parallel and series stacking combined. Figures 23 to 28 inclusive display load-deflection curves for the disc springs stacked in increasing parallel order. The corresponding stiffness values in Table 1 were calculated from the steepest portion of the plots.

LOAD HOLD CONDITION

Long term creep tests require that a given axial load be maintained on a test specimen. A steel specimen loaded in uniaxial compression was used to test the multi-use test system in this regard. At a predetermined load the Eldex hydraulic pump was stopped. Axial load, specimen strain and laboratory temperature was logged every 15 minutes. The test was started at the end of a work day and continued overnight.

Figure 29 displays specimen axial load versus time in hours. The load drops initially and then stabilizes over time. Figure 30 displays laboratory temperature versus time for the same test. The laboratory temperature initially rises and then stabilizes over night. The initial temperature rise reflects the discontinued traffic of laboratory personnel through a door to the exterior. The door is adjacent to the test area and accesses outside directly. Figure 31 displays specimen strain versus time. Laboratory temperature fluctuations do not affect the specimen strain within the resolution of the strain measuring instruments.

The load hold performance of the Eldex pump in the off condition was satisfactory. To compensate for axial load fluctuations during extreme laboratory temperature fluctuations, the in-house automatic pressure controller may be incorporated in the hydraulic loading circuit.

Table 1 Typical disc spring stiffness stacking arrangements

Springs in parallel	Springs in series	Stiffness (GN / m)
	6	0.030
	5	0.036
	4	0.045
	3	0.060
	2	0.089
	1	0.179
2		0.358
Indiana	limestone	0.386
3		0.507
Loading	frame	0.627
4		0.649
5		0.740
6		0.810
Diabase	(Quebec)	1.285
Triax piston	& platen	2.254

STIFFNESS OF ONE SPRING

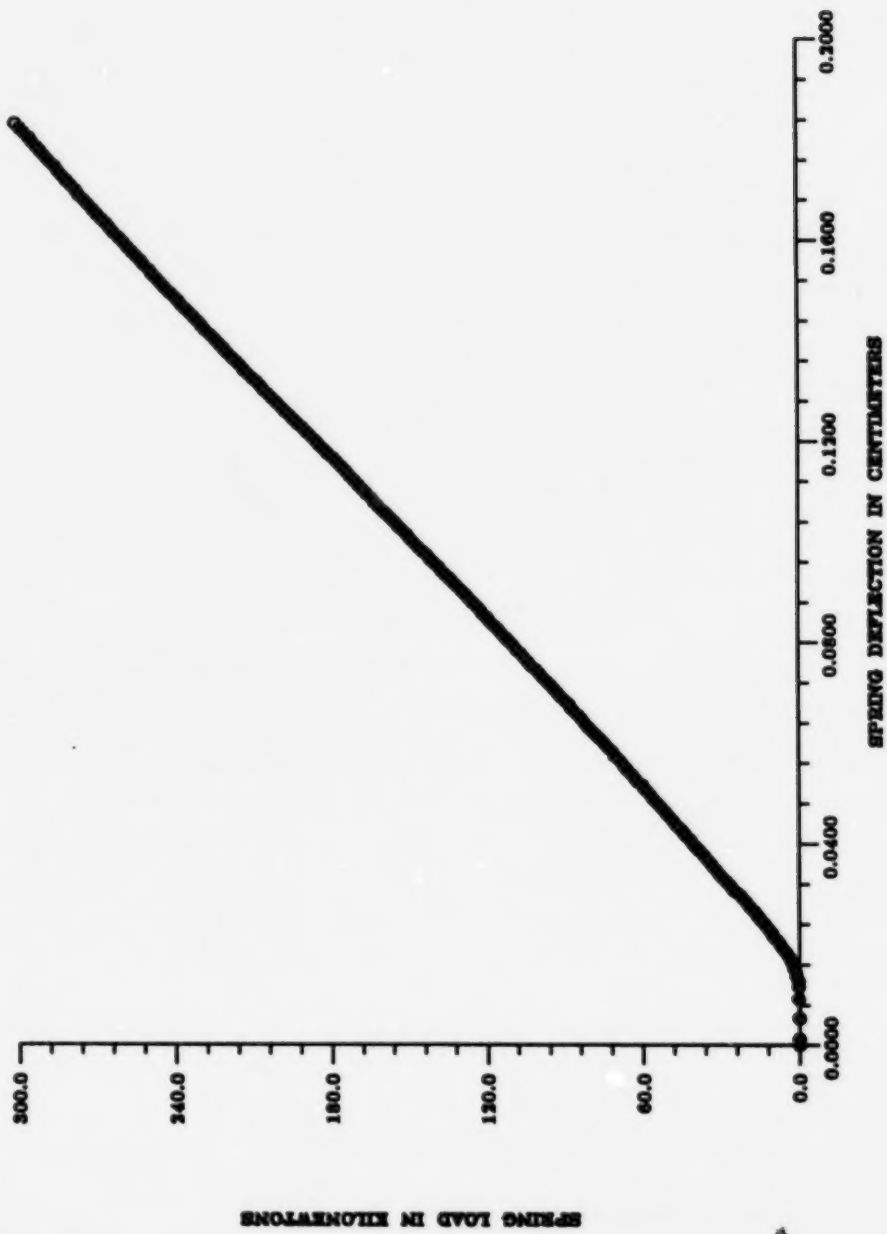


Figure 23. Load-displacement plot of one disc spring

STIFFNESS OF TWO SPRINGS IN PARALLEL

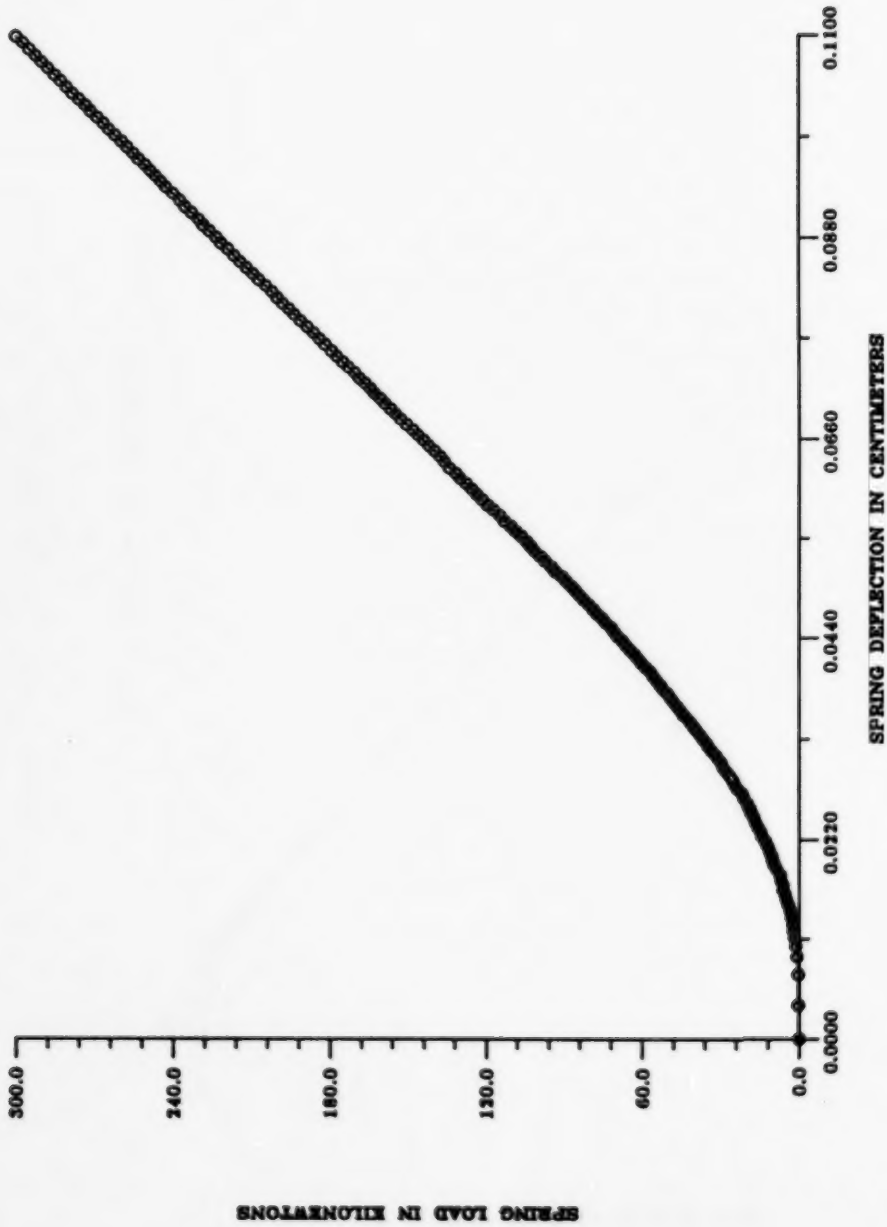


Figure 24. Load-displacement plot of two disc springs in parallel

STIFFNESS OF THREE SPRINGS IN PARALLEL

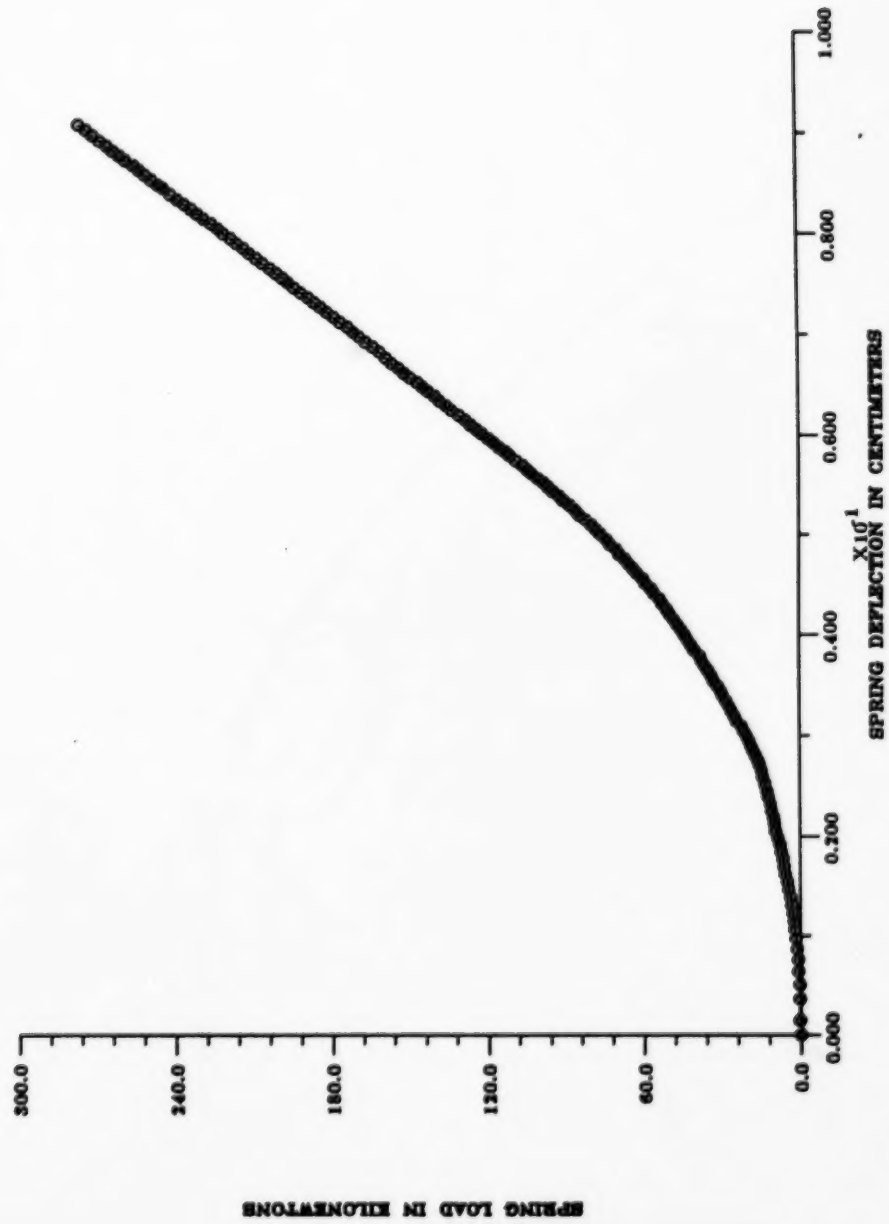


Figure 25. Load-displacement plot of three disc springs in parallel

STIFFNESS OF FOUR SPRINGS IN PARALLEL

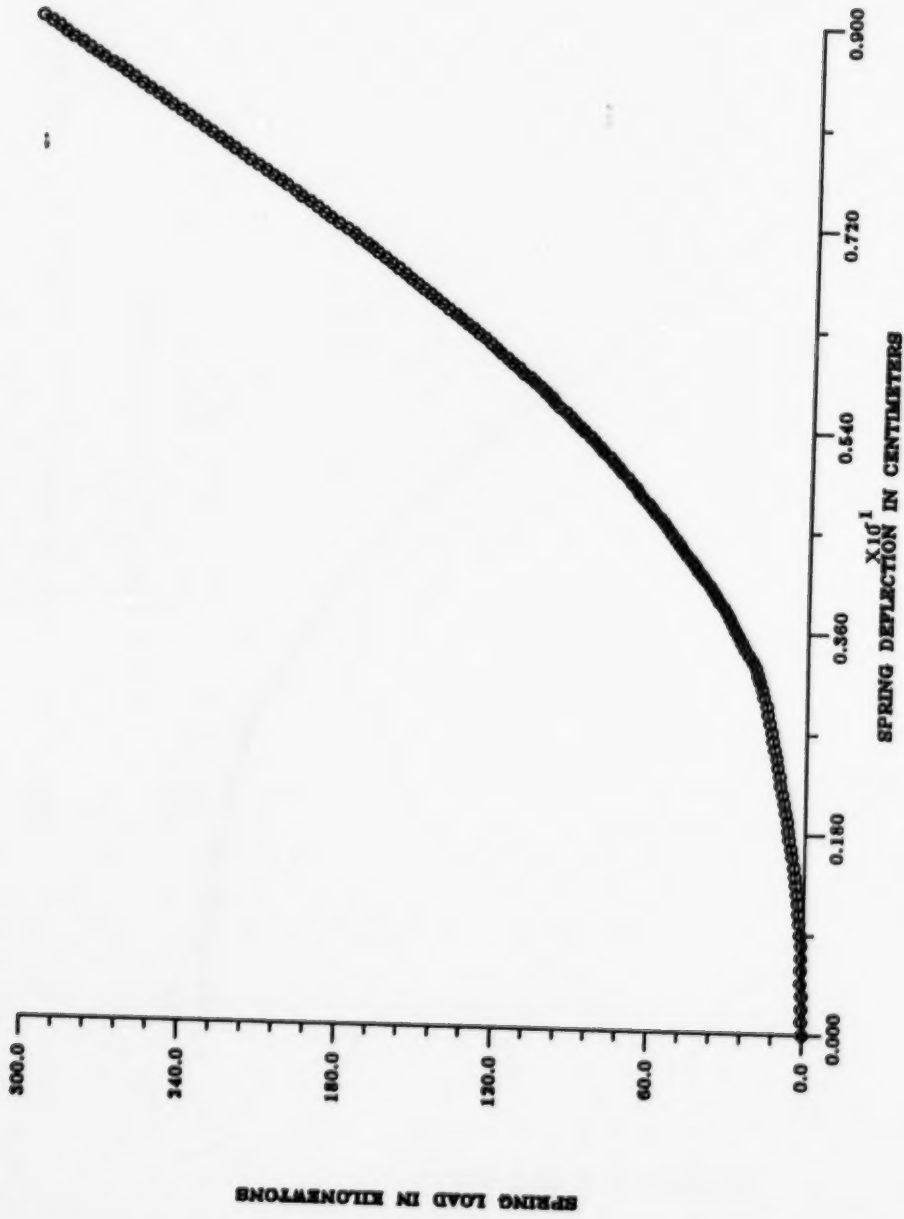


Figure 26. Load-displacement plot of four disc springs in parallel

STIFFNESS OF FIVE SPRINGS IN PARALLEL

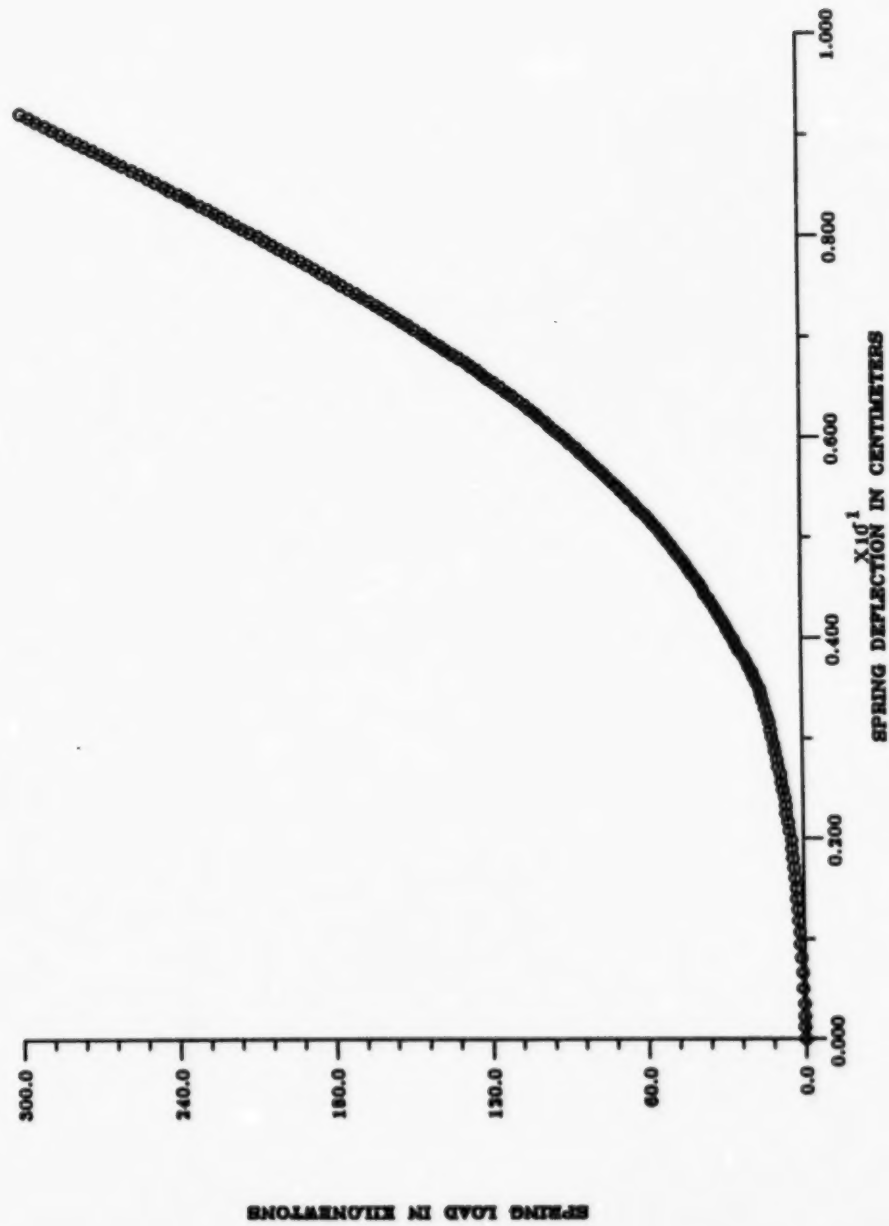


Figure 27. Load-displacement plot of five disc springs in parallel

STIFFNESS OF SIX SPRINGS IN PARALLEL

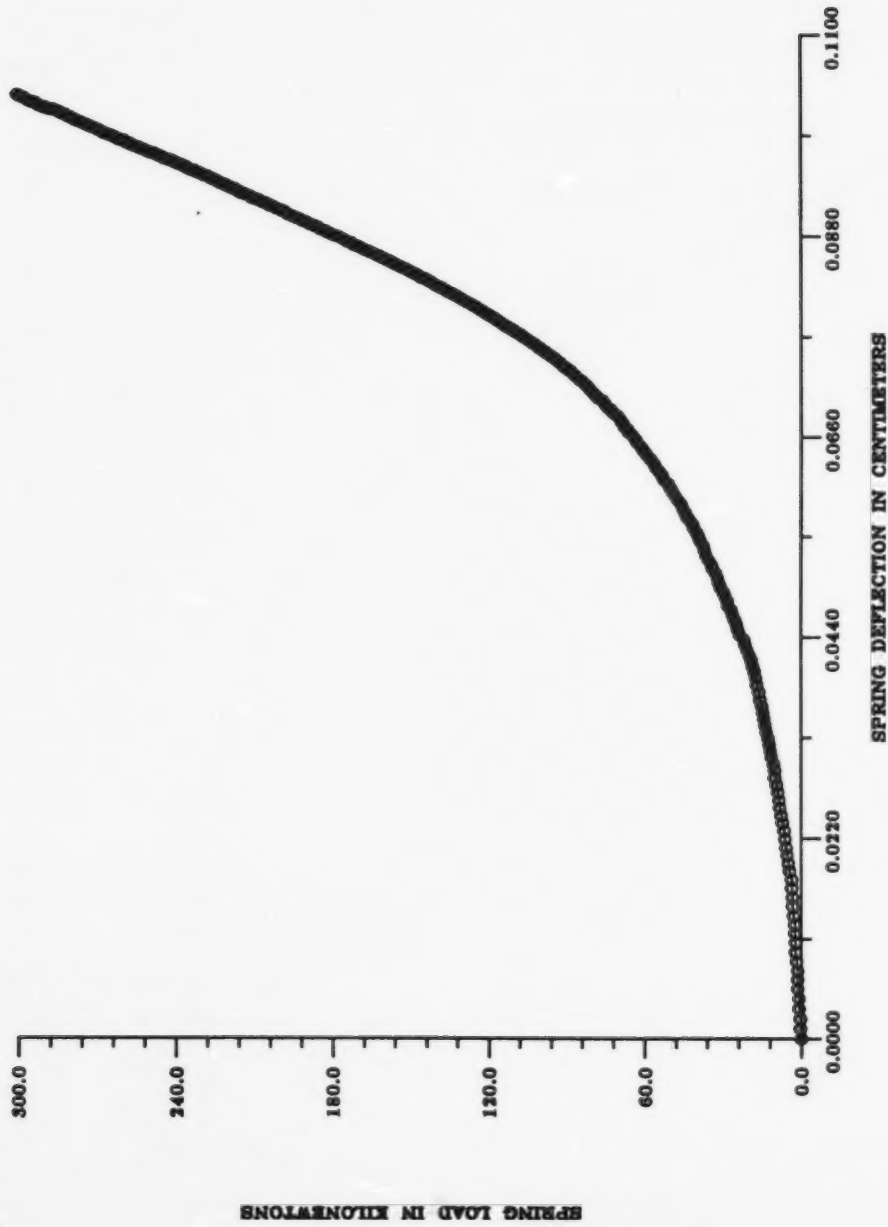


Figure 28. Load-displacement plot of six disc springs in parallel

AXIAL LOAD VERSUS TIME FOR STEEL SPECIMEN

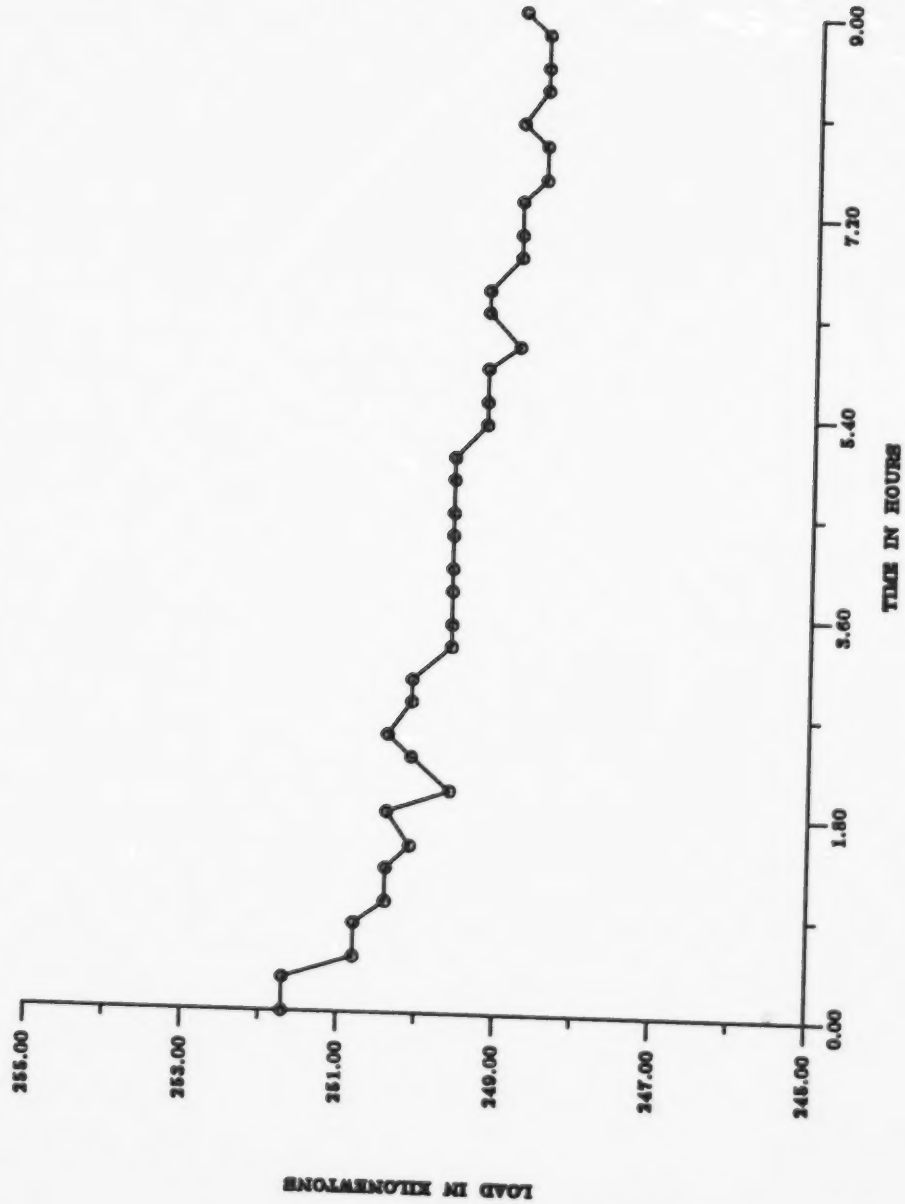


Figure 29. Load hold-time plot of steel specimen

LABORATORY TEMPERATURE VERSUS TIME FOR STEEL SPECIMEN

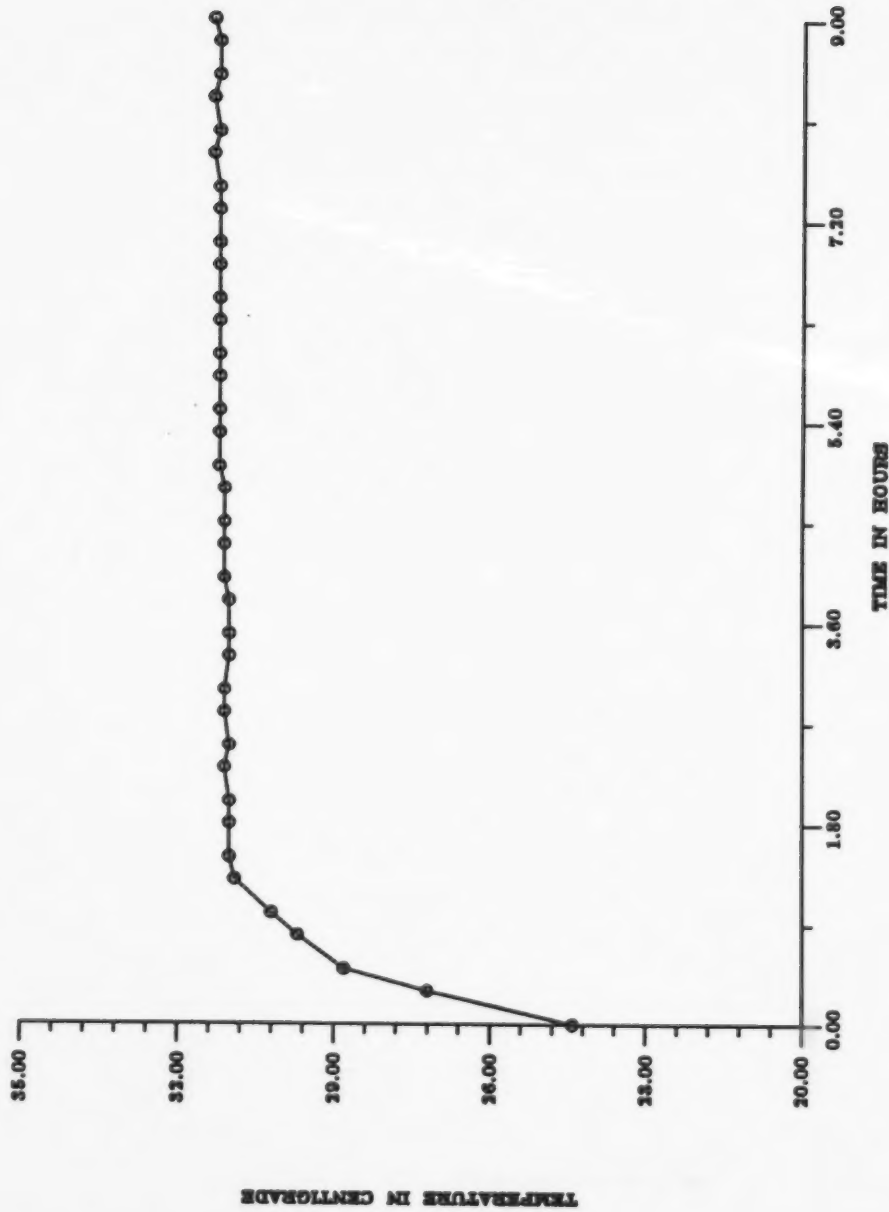


Figure 30. Laboratory temperature-time plot

AXIAL STRAIN VERSUS TIME FOR STEEL SPECIMEN

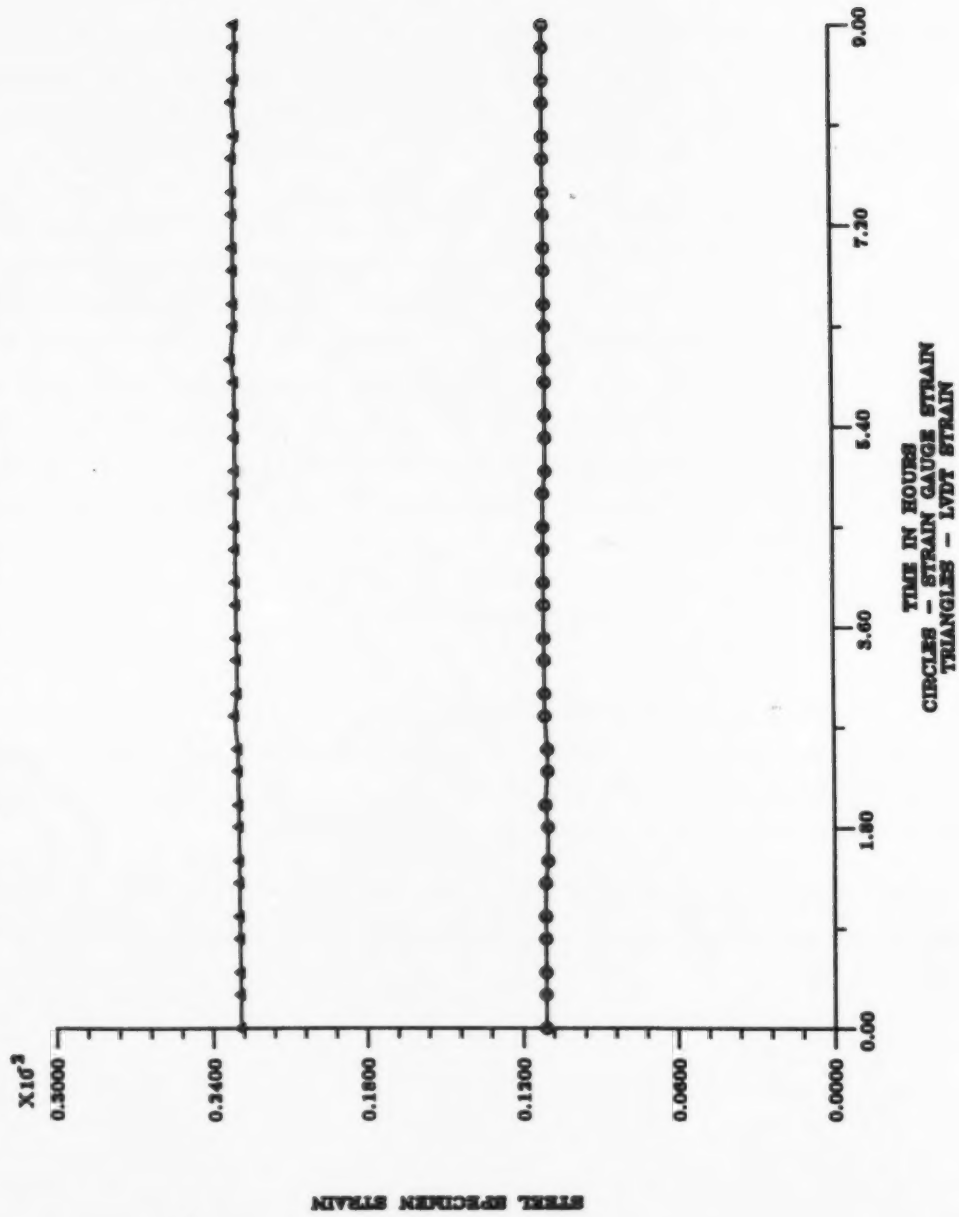


Figure 31. Strain-time plot of steel specimen

5. TYPICAL TRIAXIAL TEST

Figure 5 displays a jacketed limestone rock specimen mounted on one end of the triaxial piston ready for testing. Bicycle inner tubing was used as jacketing material. The tubing was sealed at the platen surfaces using O-rings to prevent confining fluid intrusion.

Strain gauges were not glued on rock surfaces for this triaxial test. Cut-outs through the bicycle tubing may be used to facilitate gauging of rock surfaces. The rock surfaces exposed at the cut-out locations may then be sealed from confining fluid intrusion using Dow Corning 730RTV fluorosilicone sealant.

Figure 32 displays specimen axial load versus specimen axial strain of the limestone specimen. The triaxial test confining pressure was stepped up in increments as follows: 0.35 MPa, 3.45 MPa, 6.90 MPa, 13.81 MPa and 20.71 MPa. The maximum confining fluid pressure was maintained for the duration of the test. The specimen axial load was corrected for confining fluid pressure acting on the exposed end area surface of the triaxial piston. Specimen strain readings from transducers were corrected for compression of the triaxial piston and end platen. The specimen exhibited a brittle to ductile failure transition. The results of this test are typical of those reported previously [7] using the other available test system.

6. FUTURE MODIFICATIONS

The existing Eldex hydraulic loading pump was found to be deficient in providing the maximum required loading rates. The pump will be replaced by a larger model having a flow rate variable from 0 to 100 cc / minute. The maximum loading rate will then be increased to 724 micrometers / second.

A 152 mm diameter suspended spherical seat has been ordered to compensate for misalignment of the test system crosshead during loading. Full specimen end bearing is then ensured.

TRIAXIAL TEST - LOAD VERSUS STRAIN

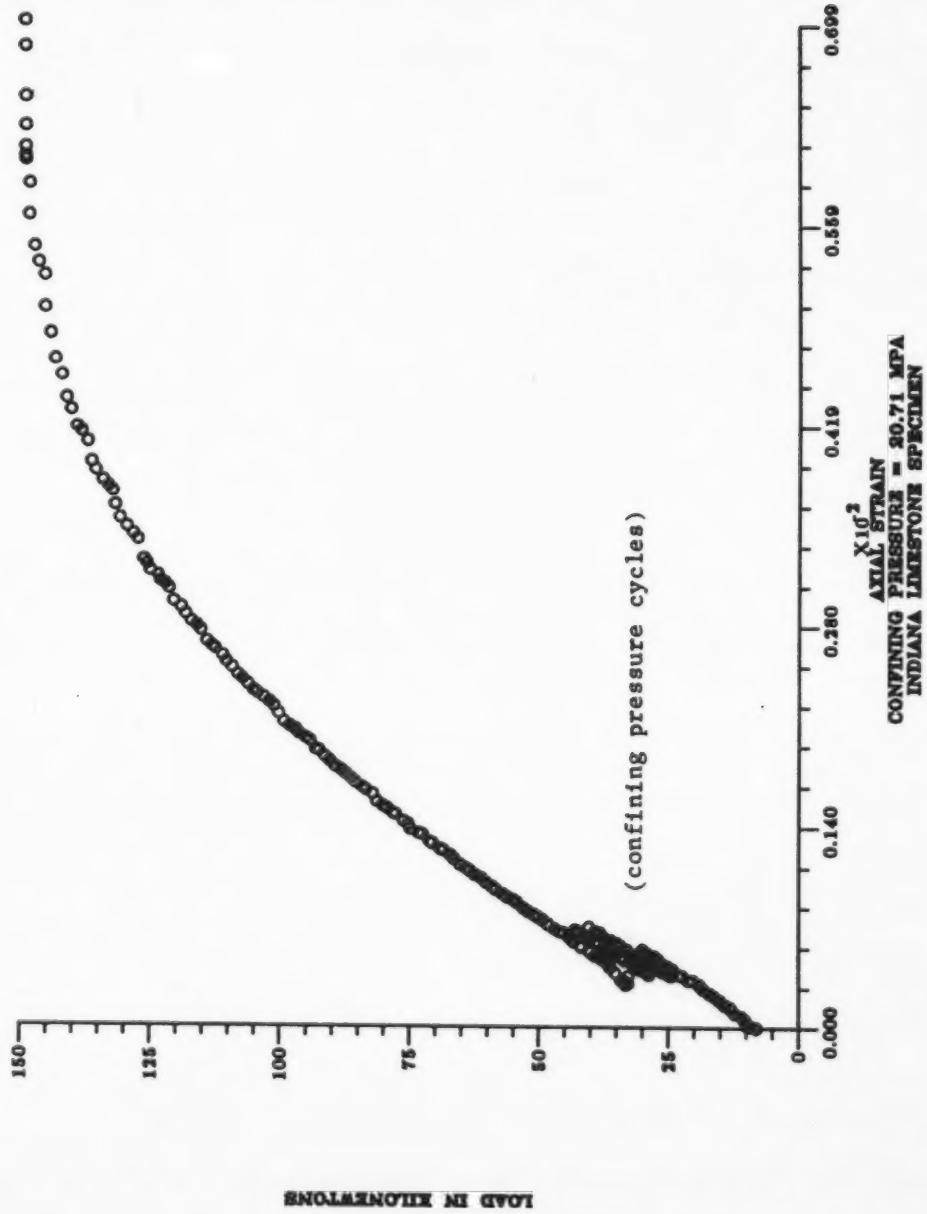


Figure 32. Triaxial load-strain plot of limestone specimen

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